The XMM Cluster Survey

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Ed Lloyd-Davies	University of Sussex	UK
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Pedro Viana	Universidade do Porto	Portugal
Mike West	European Southern Observatory	Chile

Talk overview

- Introduction
  - Galaxy clusters
- The XMM Cluster Survey
  - Cluster detection
  - Optical follow-up
  - First data release
- Future science
  - Cosmological constraints
  - Scaling relations

Galaxy clusters

- Largest gravitationally bound objects in the universe
- Cosmological probes
- Independent and complementary constraints
- Laboratories galaxy evolution
- $M \sim 10^{14\text{-}15}\ M_{solar}$
- Galaxies 5%; hot intracluster medium 15%; Dark matter 80%
- Detected in optical; weak or strong lensing; SZ effect; X-rays

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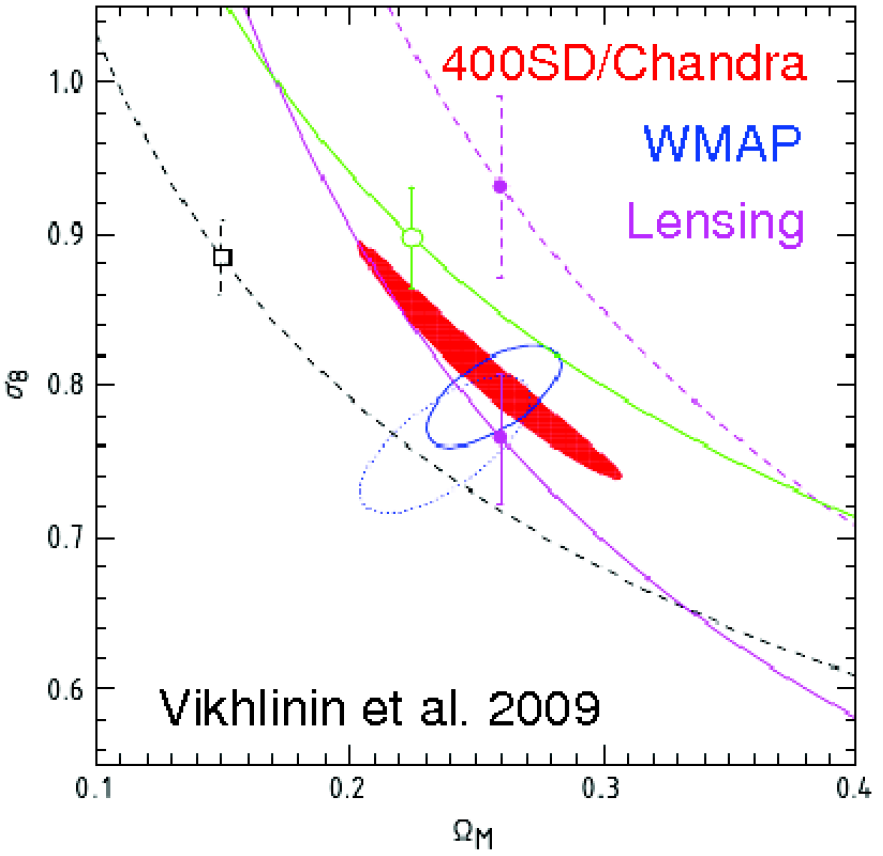
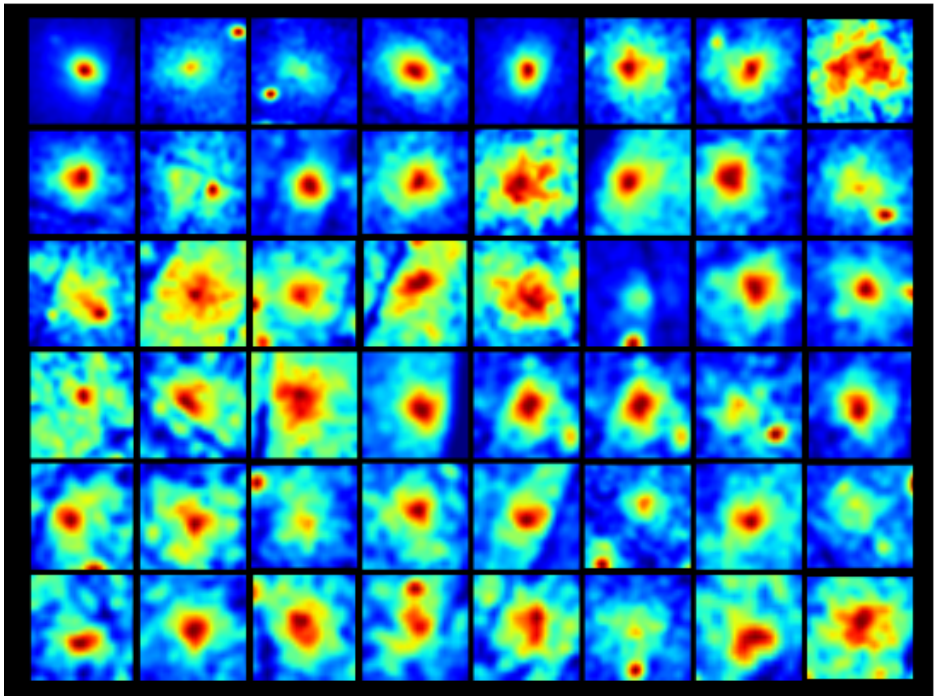


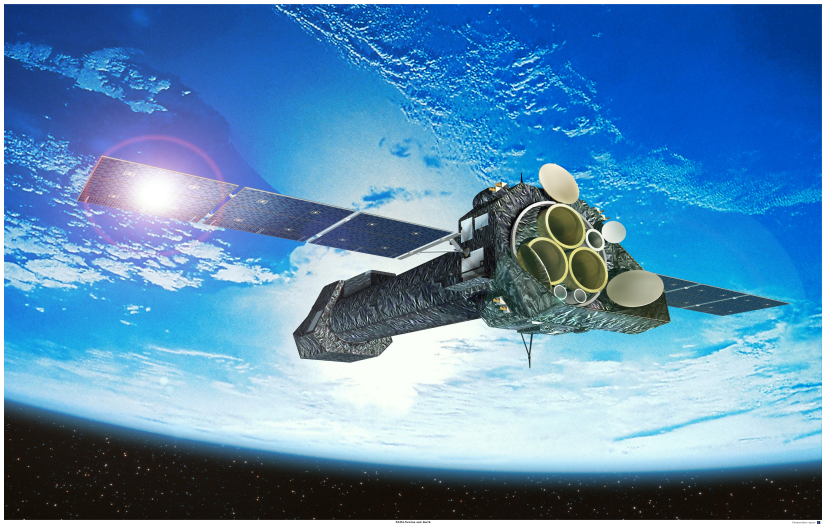
Galaxy clusters in X-rays

- ICM at $T \sim 10^7 k$.
- Bremsstrahlung emission $\sim n_e^2$
- High contrast against sky -less prone to projection effects.
- X-ray properties correlated to mass
    - $Tx \sim M^{2/3}$, $Lx \sim M^{4/3}$; $Lx \sim Tx^2$



X-ray cluster surveys

- XMM Newton
  - Sensitive, large FOV, Spectral imaging capabilities.
  - XMM-LSS (Pierre et al. 2006; Pacaud et al. 2007; XDCP (Fassbender et al. 2010); XMM-COSMOS (Finoguenov et al. 2007); SXDS (Finoguenov et al. 2010)
  - **… and XCS** (Lloyd-Davies et al. 2010; Romer et al. 2001)
- Chandra
  - High spatial resolution, not as sensitive.
  - CHAMP (Barkhouse et al. 2006).



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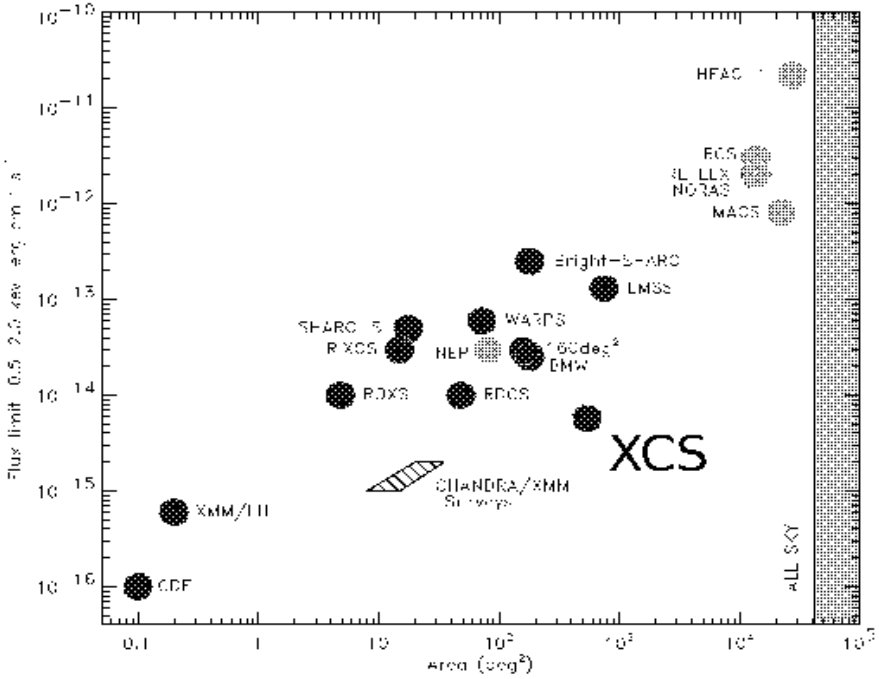

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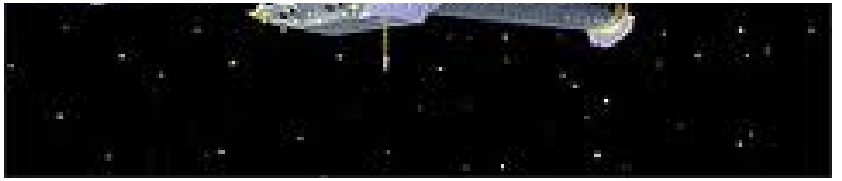
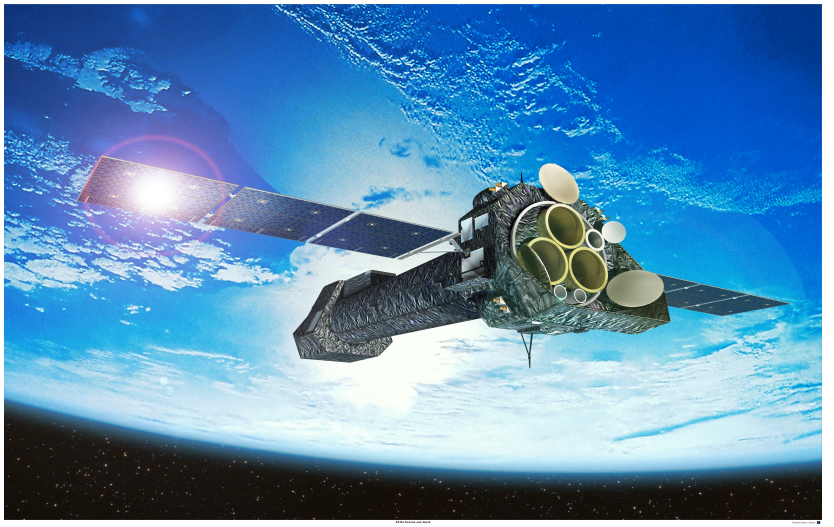


X-ray cluster surveys

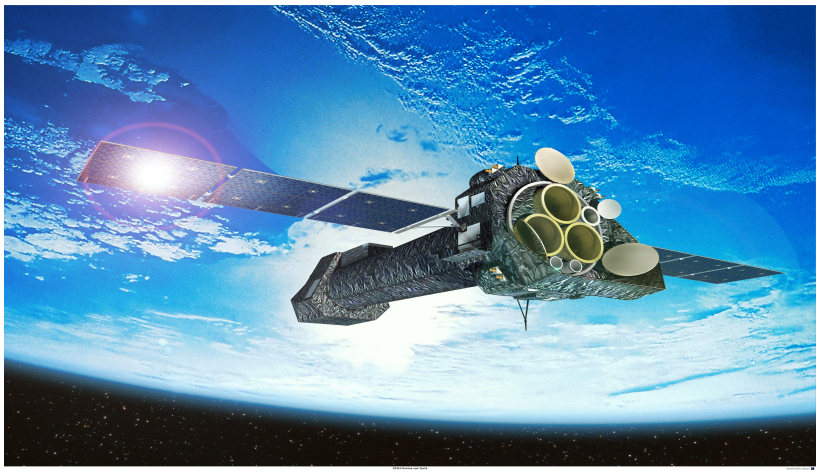
Next X-ray mission >2020.

- Emphasis on upcoming optical surveys (pan-STARRS, DES).
- But optical surveys need mass proxies.
- Provided via X-ray to optical scaling relations.



XCS

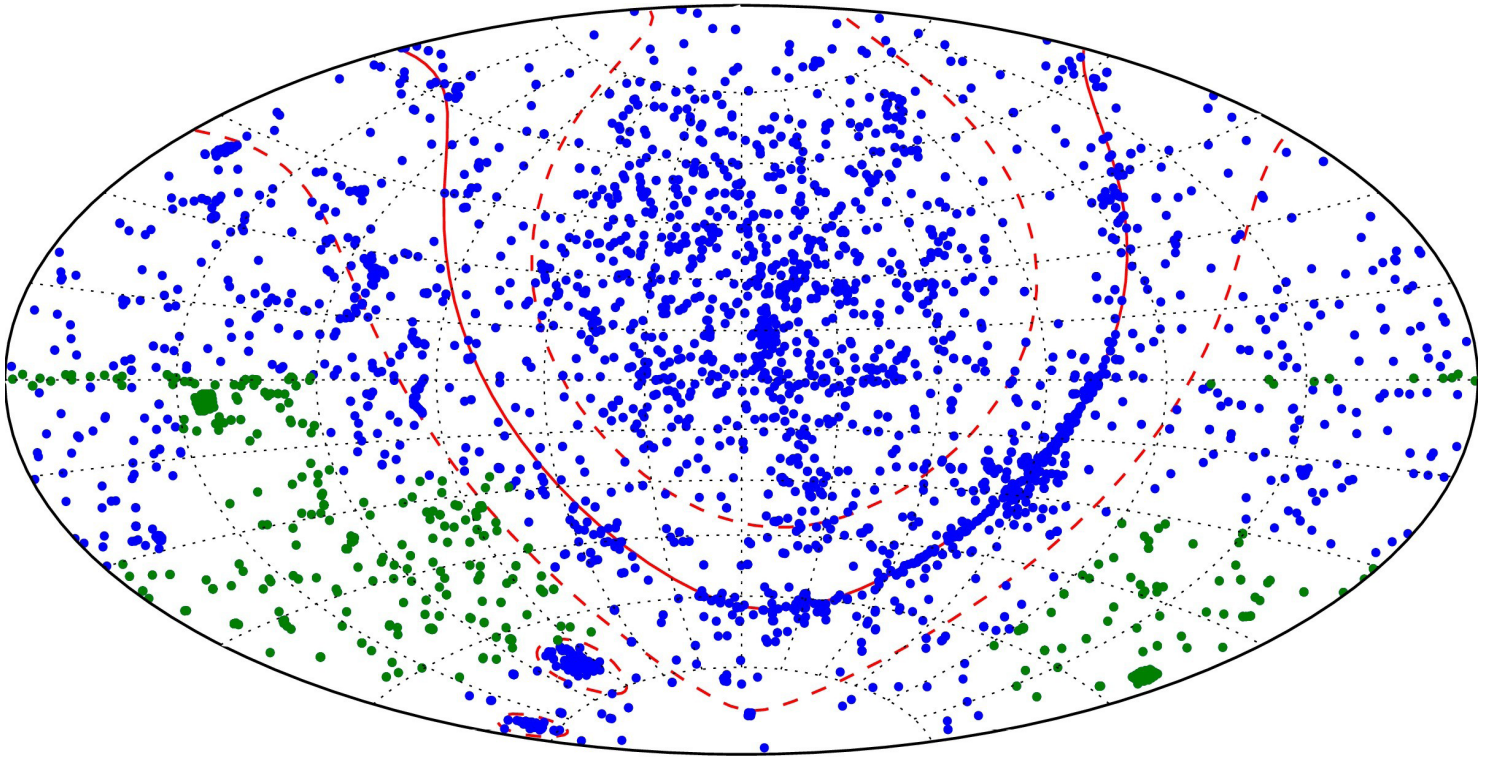
XMM Cluster Survey



- Serendipitous X-ray cluster survey
- XMM-Newton Public Archives.
- Final area ~500 deg^2 (serendipitous)
  - Flux limit $5x10^{14}$ erg s^{-1} cm^{-2}
  - Typical exposure times 10ks.
  - Enables detection of z>1 systems (e.g. XMMXCS J2215 z=1.46; Stanford et al., 2006; Hilton et al., 2009;2010)
- Science Goals:
  - Cosmological parameters σ_8, Ω_M, Ω_Λ to 5, 10 and 15 percent accuracy respectively.
  - Cluster scaling relations and their evolution (e.g. Lx-Tx, Lopt-Tx, Ngal-Tx).
  - Use high redshift clusters to study theories on galaxy evolution and formation.

XCS

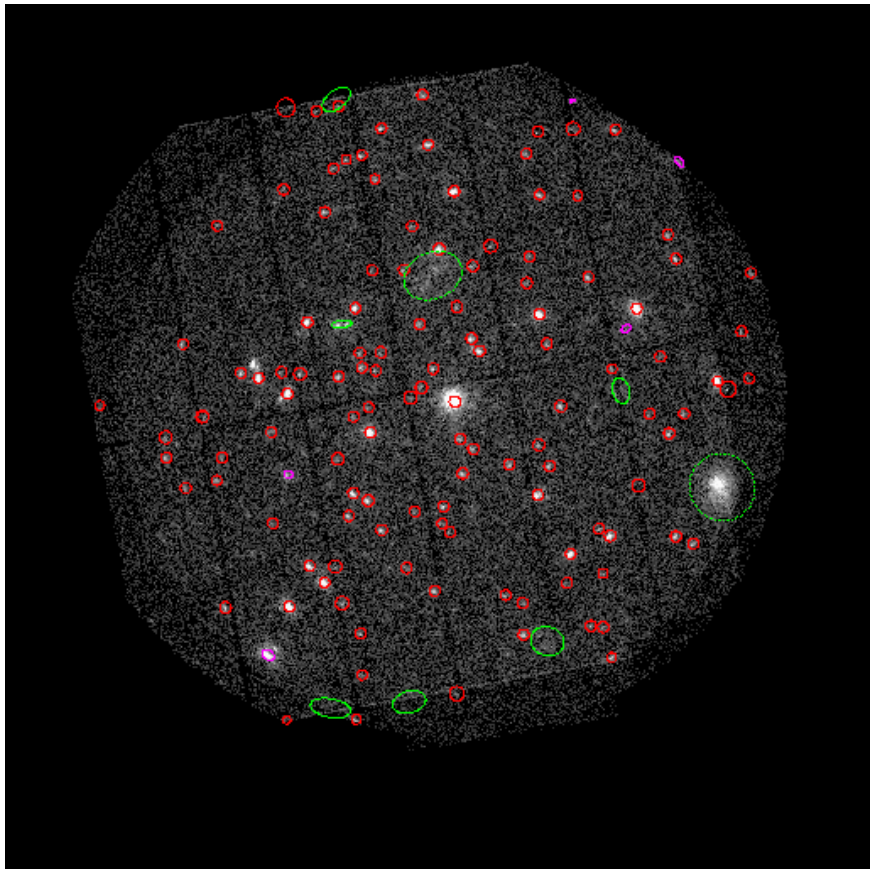
XMM Cluster Survey



- 5776 Observations processed (21st July 2010).
- Targetted pointings, Galactic plane, Megallanic clouds excluded.
- 410 deg² statistical area available for cluster finding.

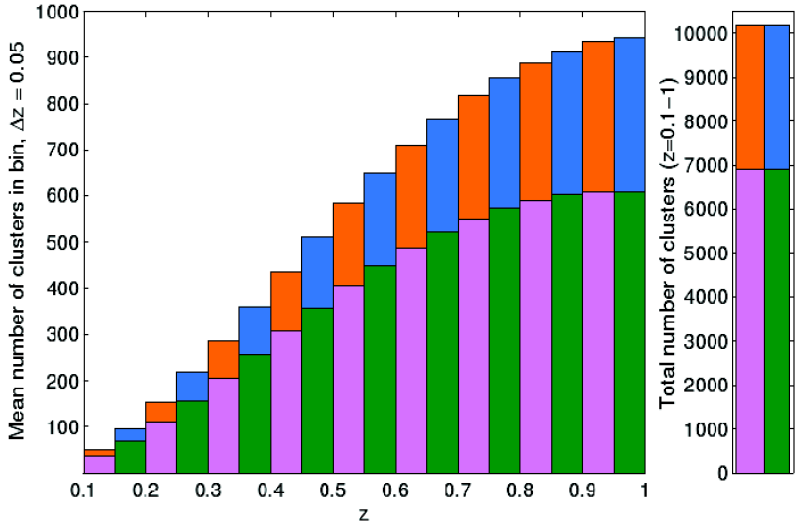
XCS
XMM Cluster Survey

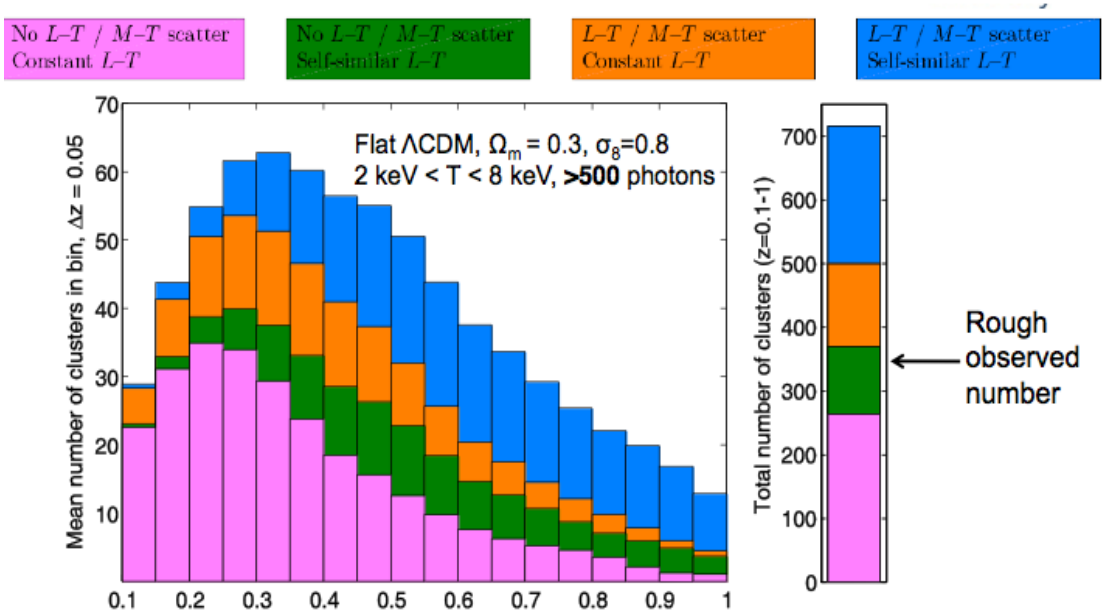
Automated pipelines



- **XCS image creation**.
  - 5642 obsIDs
- **Source detection and classification.**
  - Wavelet algorithm
  - 3669 cluster candidates
  - 1022 able to measure Tx
- **Source properties:**
  - NED z search (154 known)
  - Spatial fitting Lx (ongoing)
  - Spectral fitting Tx (517)
  - X-ray redshifts zx ($\Delta z=0.15$)

Selection Function





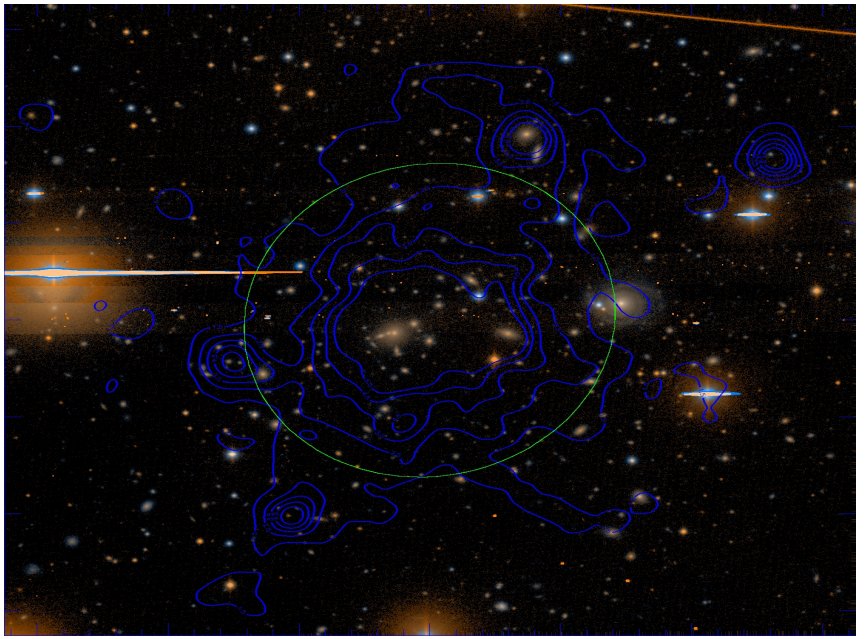
- Underlying distribution of clusters before and after folding in selection function
- Expected for clusters in 500 deg^2 with >500 counts (Sahlen et al. 2009)

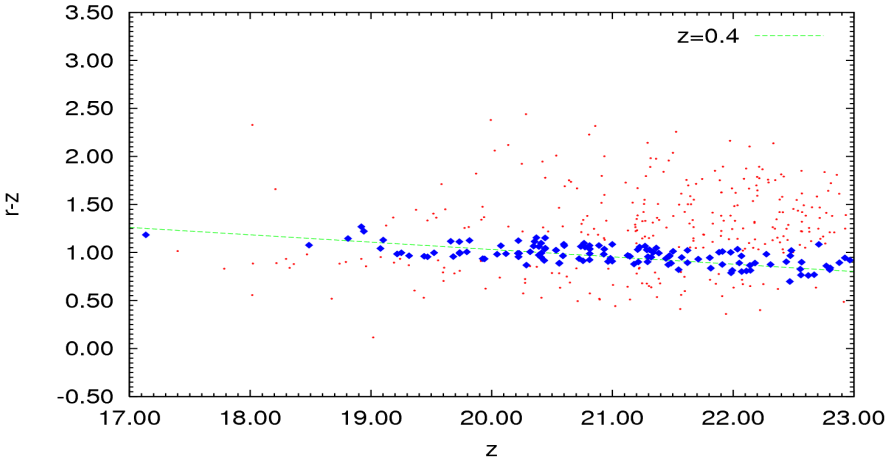
XCS NEEDS REDSHIFTS!

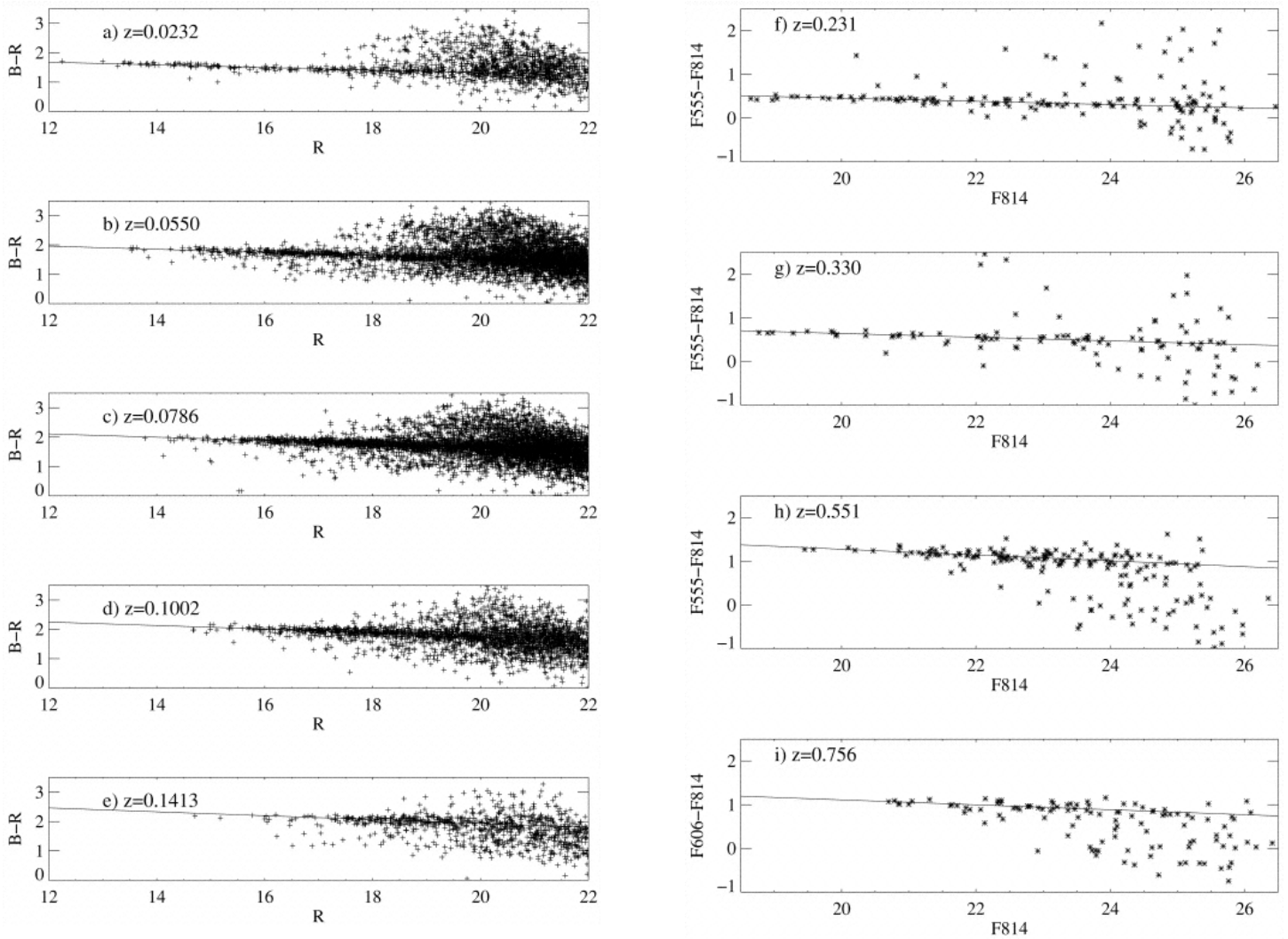
- Need to confirm clusters and assign redshifts.
- Spectra too time consuming; imaging cheaper and more efficient.
- Main method: use 2 band wide field imaging and exploit universal red-sequence relation within clusters (i.e red-sequence technique).
- Redshift sources:
  - Dedicated follow up survey NXS (2 band imaging).
  - ~ half area covered by SDSS DR7.
  - SDSS Stripe 82 co-add.
  - Targeted spectroscopic follow up (Keck, WHT, NTT, Gemini, Suburu).

What is a red-sequence?

- Galaxy clusters exhibit a morphology-density relation.
- The core of clusters consist of old passively evolving elliptical galaxies
- Coeval, formed from the same stellar population
- Exhibit tight relation in colour-magnitude space; the red-sequence.
- Red-sequences are very homogeneous within a cluster and between clusters.







- Evolves passively up to z=1.3. Implies old passively evolving ellipticals, z_f~>2
- Slope = mass-metallicity relation (Kodama & Arimoto 1997)
- scatter=age effects (Kodama et al. 1999)
- zero-point= bulk properties of the stars -> redshift estimator. Fig. Gladders et al. 1998

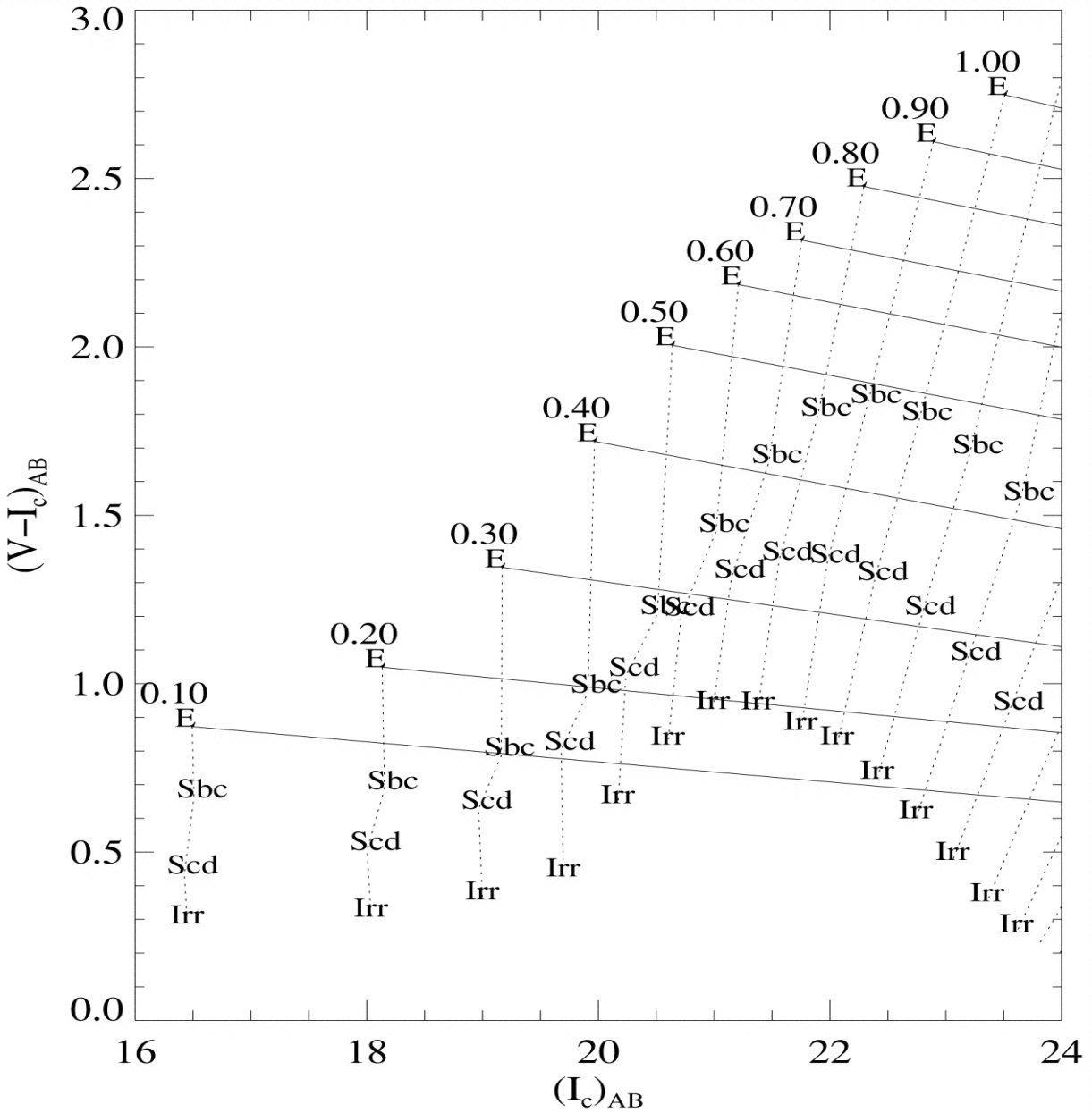


FIG. 2. Simulated (V-IC)AB vs. (IC)AB color-magnitude diagram. Model apparent magnitudes and colors at various redshifts for several types of galaxies at a fixed MI of -22. The dotted lines connect galaxies at the same redshift. Solid near-horizontal lines show the expected slope of the red sequence at each redshift. (Gladders and Yee 2000)

- Elliptical galaxies are the reddest galaxies at a given redshift, and all lower redshifts.
- Using 2 filters straddling the 4000A break provides a powerful tool for detecting clusters in optical surveys (Gladders and Yee 2000).

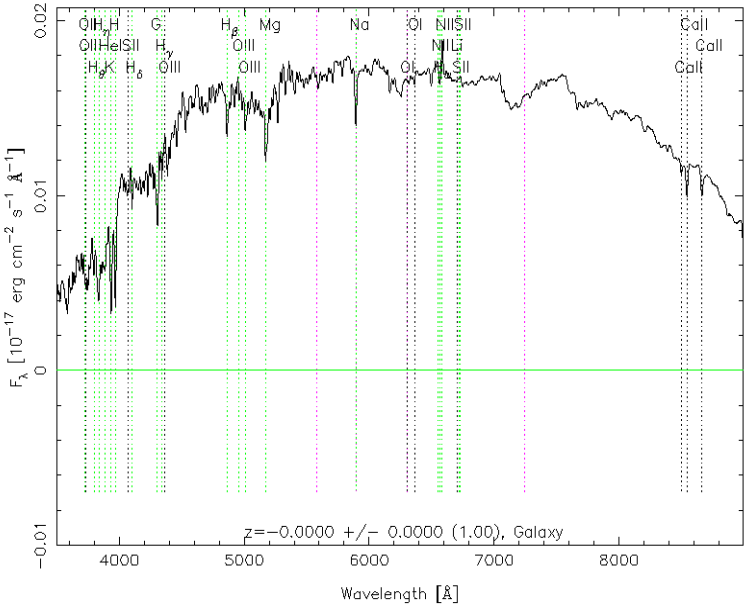


Fig. 3. SDSS spectral template of an “early-type” galaxy.

NOAO XMM Cluster Survey (NXS)

- Dedicated optical follow-up survey to XCS.
- Goal: Identify clusters and measure cluster photometric redshifts via their red sequence.
- NOAO 4m Mayall telescopes at KPNO, Arizona; and CTIO, Chile.
- 46 nights; 7 observing runs. (4 northern winter, 3 southern winter)
- Aim: image ~330 XCS fields; ~500 clusters.
- Wide field Mosaic CCD imaging. 36' x 36' f.o.v. encompassing 1 XMM-Newton field) generally containing multiple candidates.
- Image clusters to z=1
- Acts as screen for high redshift clusters followed up at Keck.

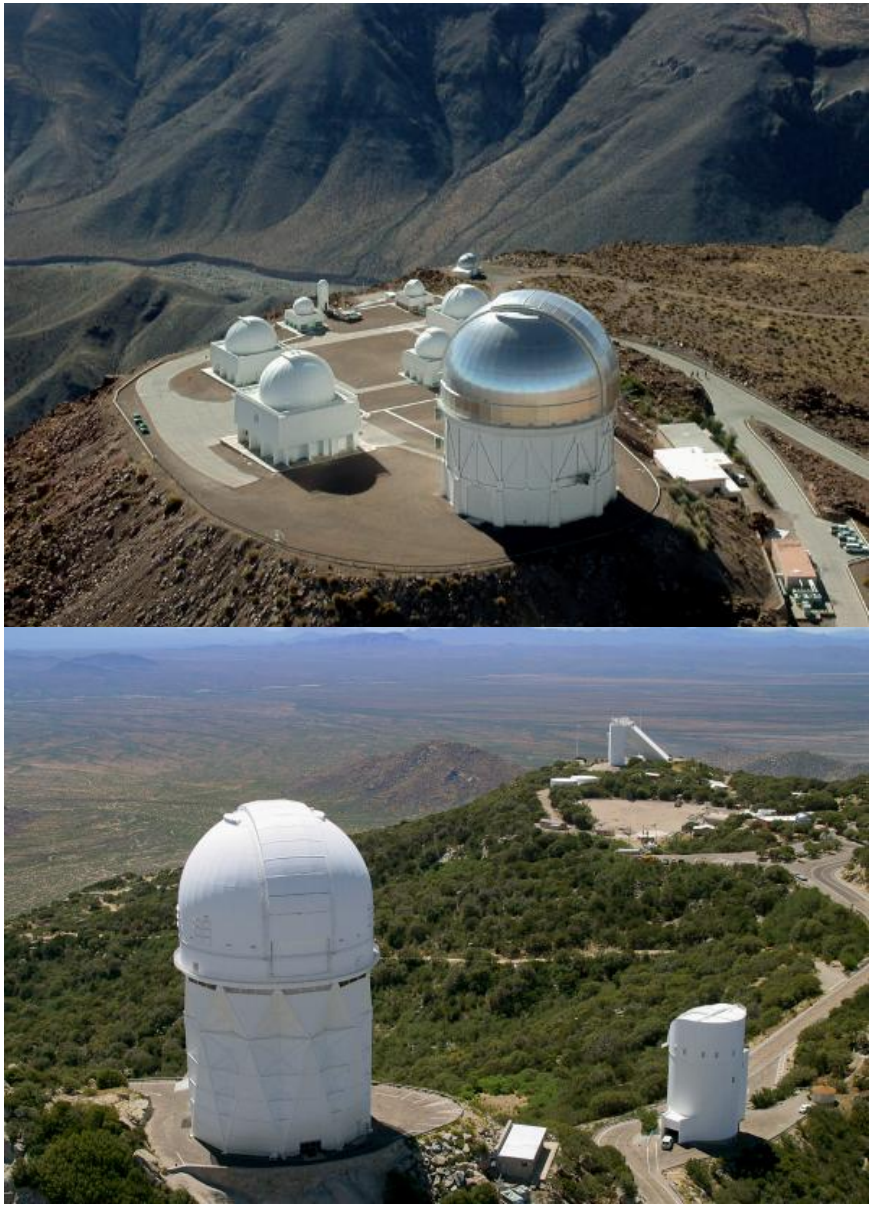


Image credit: NOAO/AURA/NSF

NXS Observing Strategy

- CCD mosaic imaging in the r-band and z-band filters chosen to provide maximum separation at z~0.5.
- Two 600s exposures in r', three 500s exposures in z' (three exposures to reduce high background levels).
- Dithering to eliminate chip gaps in final stacked image.
- Depth: r ~24.7, z~22.2 at 10σ.
- Priority to XCS500 clusters. Lower priority assigned to fields with SDSS, INT coverage.
- XCS pipeline written for completeness; use existing optical data as a preliminary screen for follow up targets.

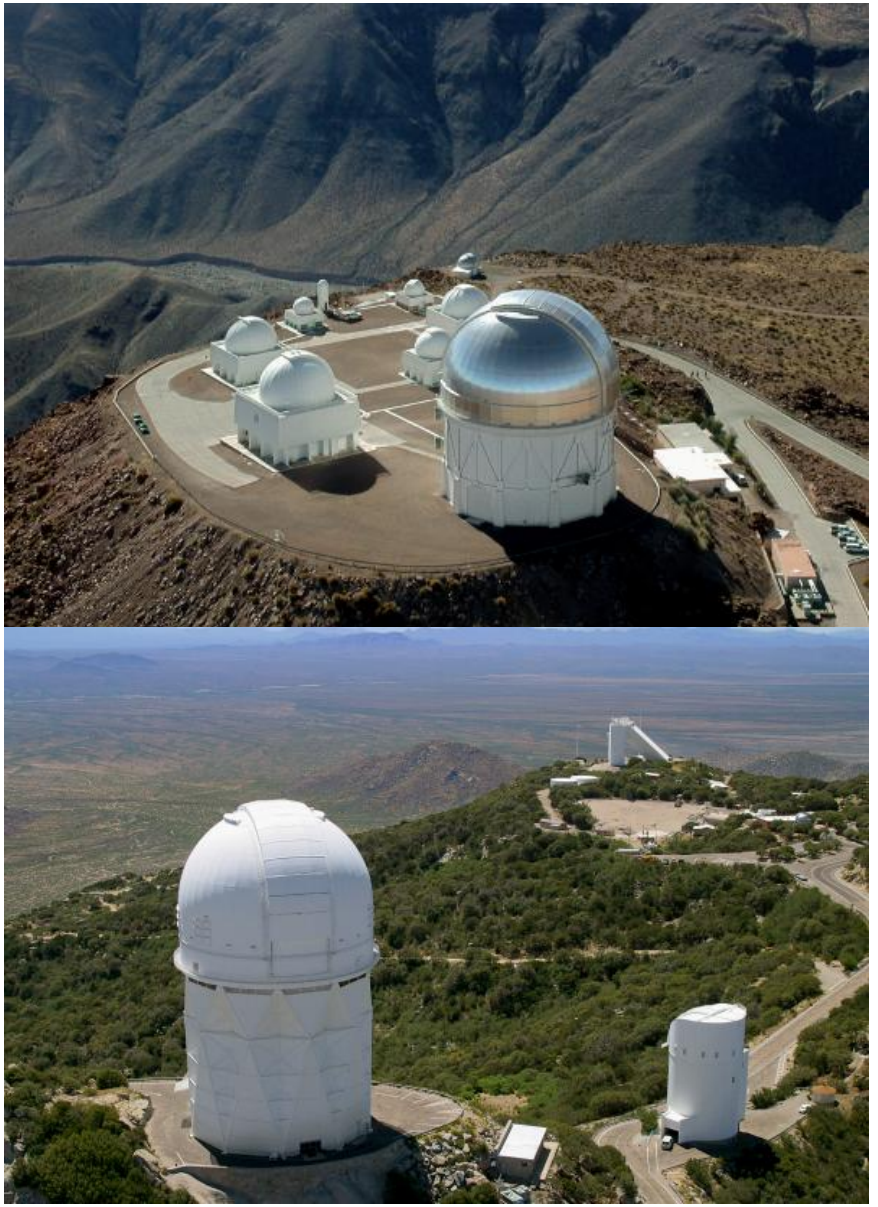
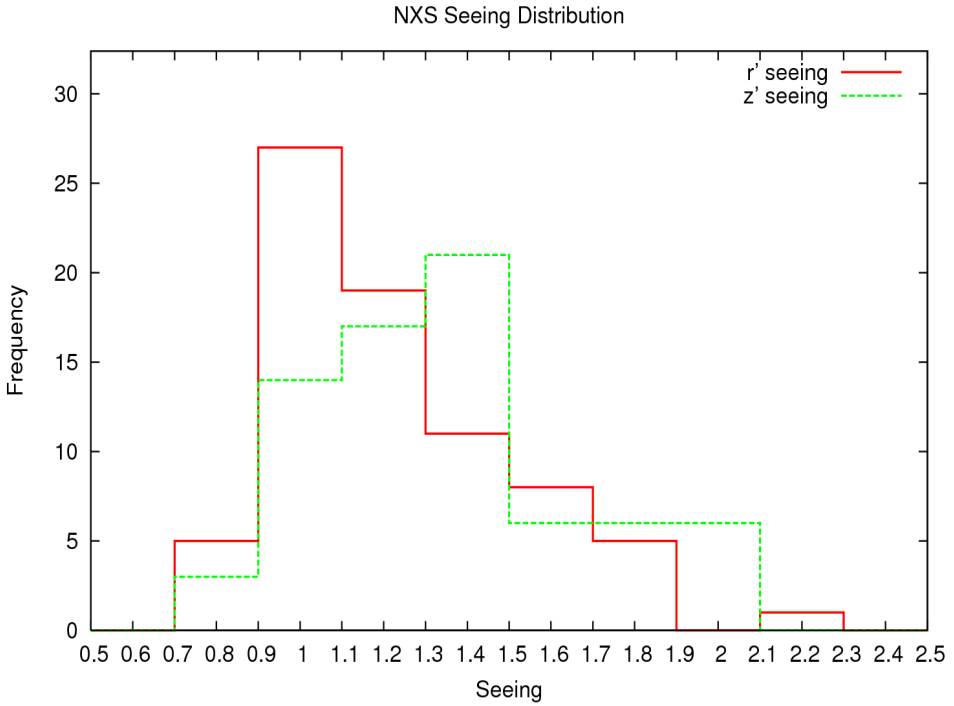


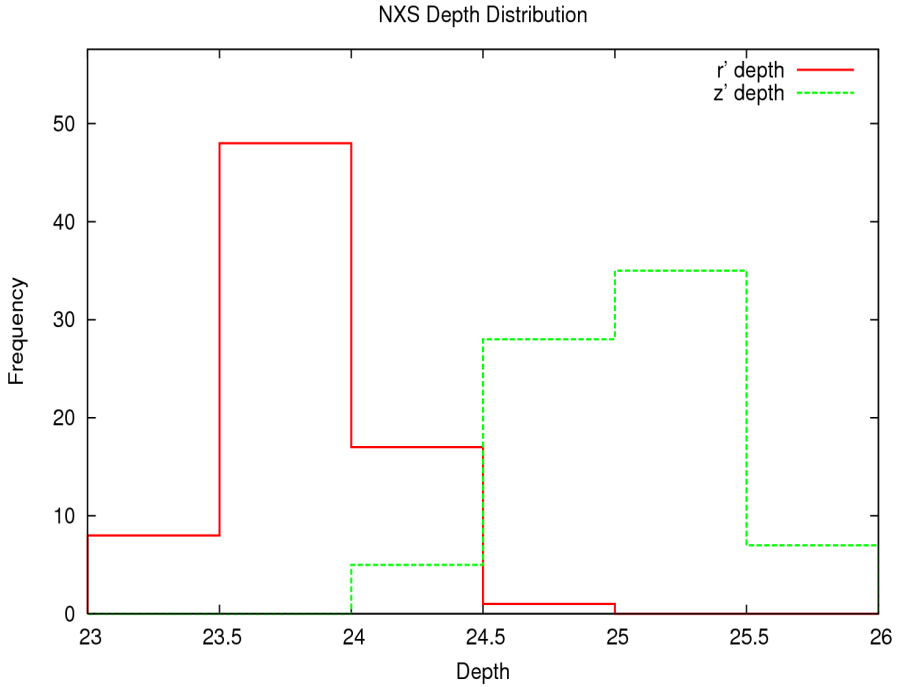
Image credit: NOAO/AURA/NSF

NXS observed

- 154 XCS fields observed
  - 609 cluster candidates
- 111 photometrically calibrated
  - 473 cluster candidates
- Typical seeing: r=1.39''; z=1.23''
- Typical depth: r=25.00; z=23.79

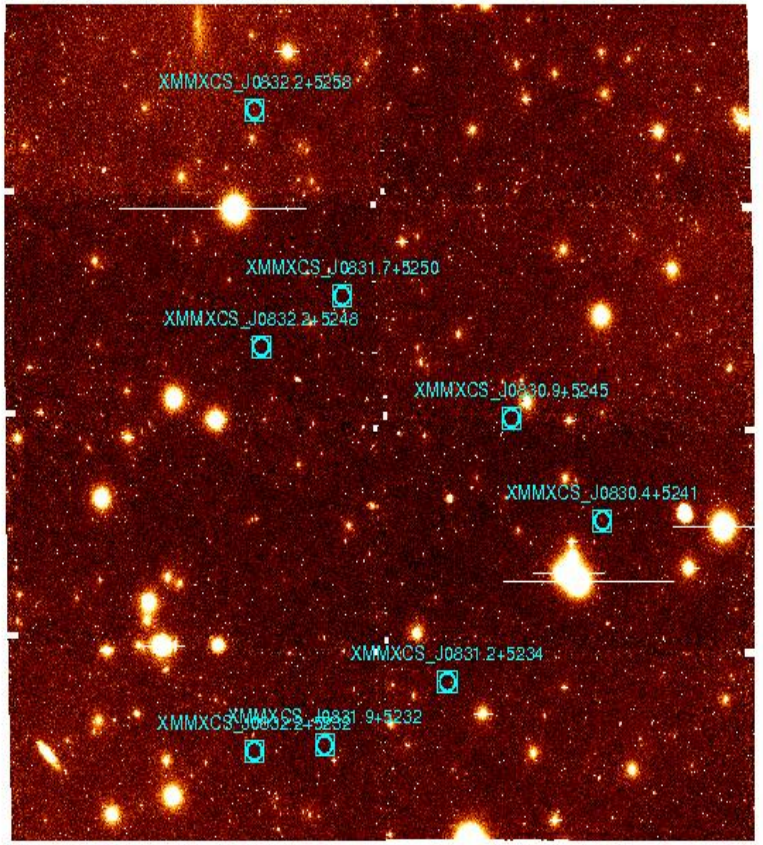
NXS observed





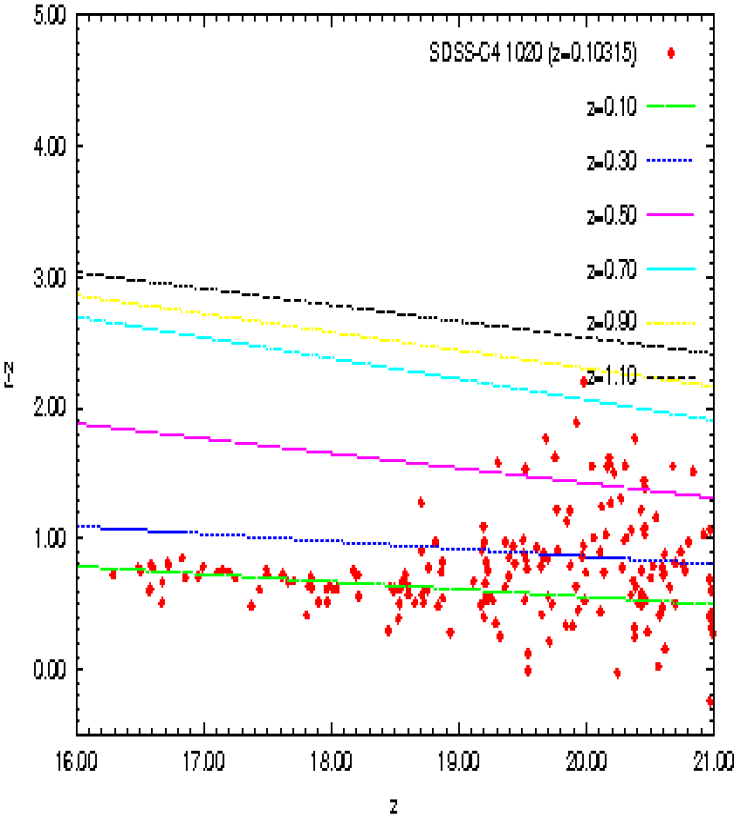
Data reduction and object catalogs

- Following the NOAO Deep Wide-Field Survey MOSAIC Reduction procedures.
- Reduction using IRAF's MSCRED package -attempts to treat handling of mosaic field as a single CCD image.
- Difficulties: pupil ghost (KPNO only), z-band fringing, WCS position offsets between r and z-band.
- Catalogs created with SExtractor.
- Star-galaxy separation using the concentration parameter C (Metcalfe et al.,1991)
- Apply atmospheric extinction and Schlegal dust map corrections.
- zeropoints determined using a combination of standard stars, sdss coverage, NXS standard star fields.



NXS Redshift Algorithm

- The model:
  - Model evolved with redshift using Bruzual and Charlot 2003 population synthesis code with a 0.1Gyr burst and Salpeter IMF at z_f=2.5
  - Empirical red sequence model calibrated to reproduce the red sequence of an average low redshift cluster z=0.1-0.11 from the SDSS C4 catalog (Miller et al. 2005).



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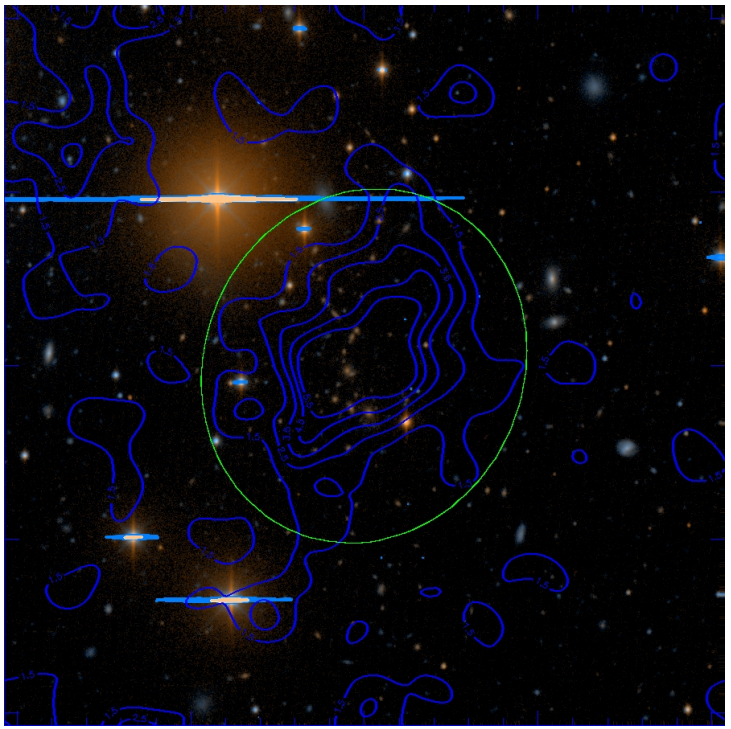


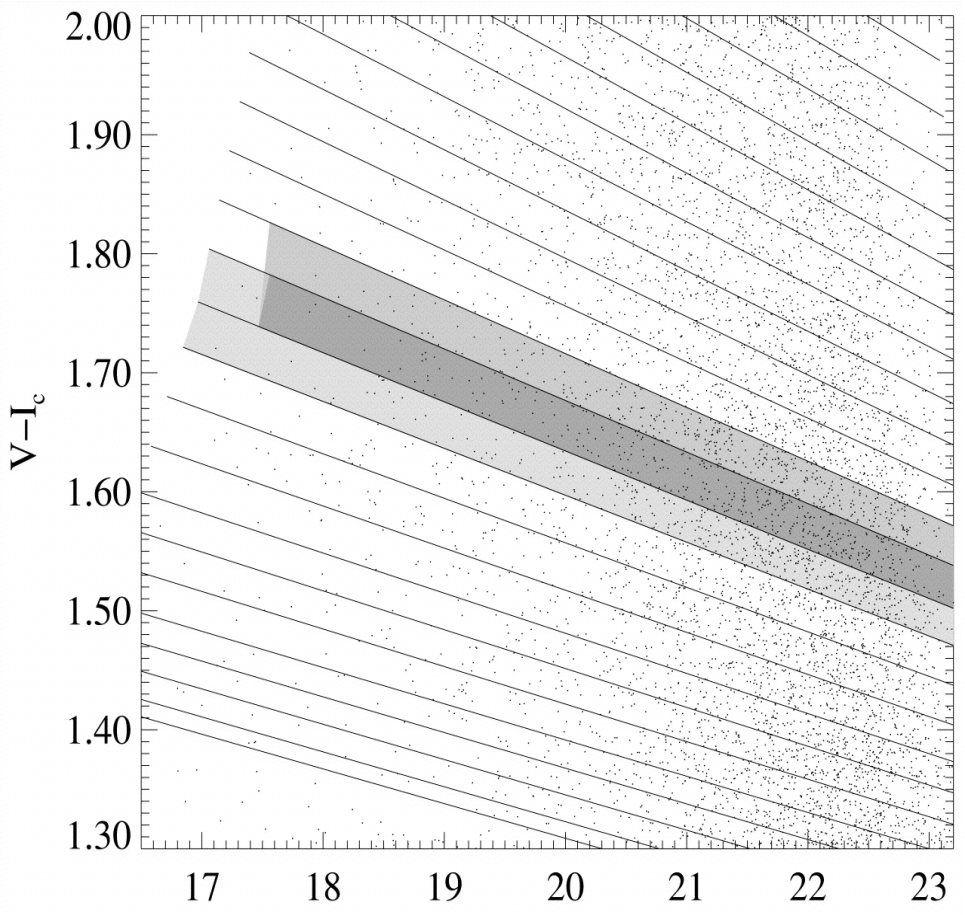


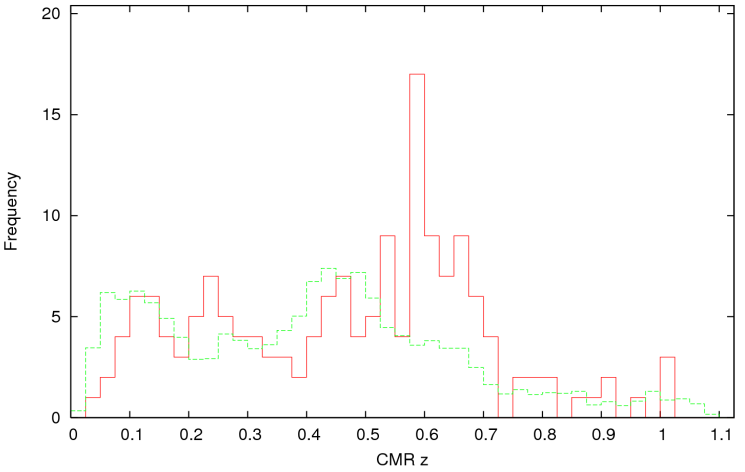
FIG. 3. Portion of the observed V-IC vs. IC CMD for the CNOC2 Redshift Survey patch CNOC0223+00. Bounding red sequences, constructed as detailed in the text, are shown as solid lines, from M*-1 to the survey limits. Two overlapping color slices (shaded regions) are highlighted, with the overlap region a darker shade. For clarity, the shading in the second slice has been set 0.5 mag fainter than that in the first slice.

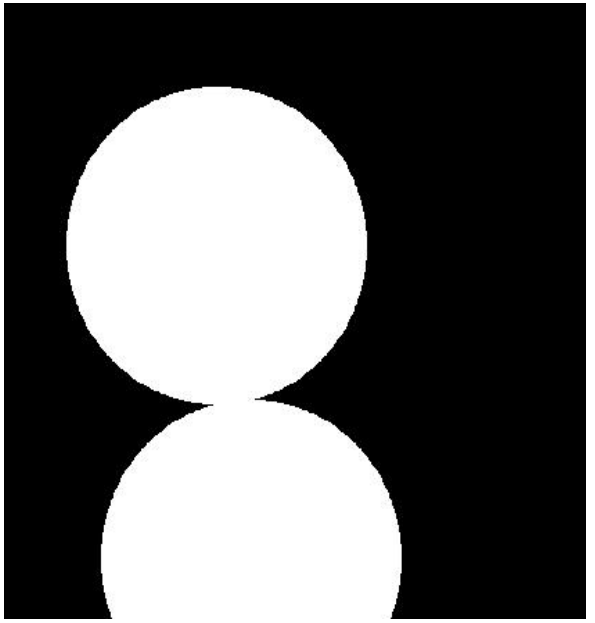
Gladders and Yee 2000.

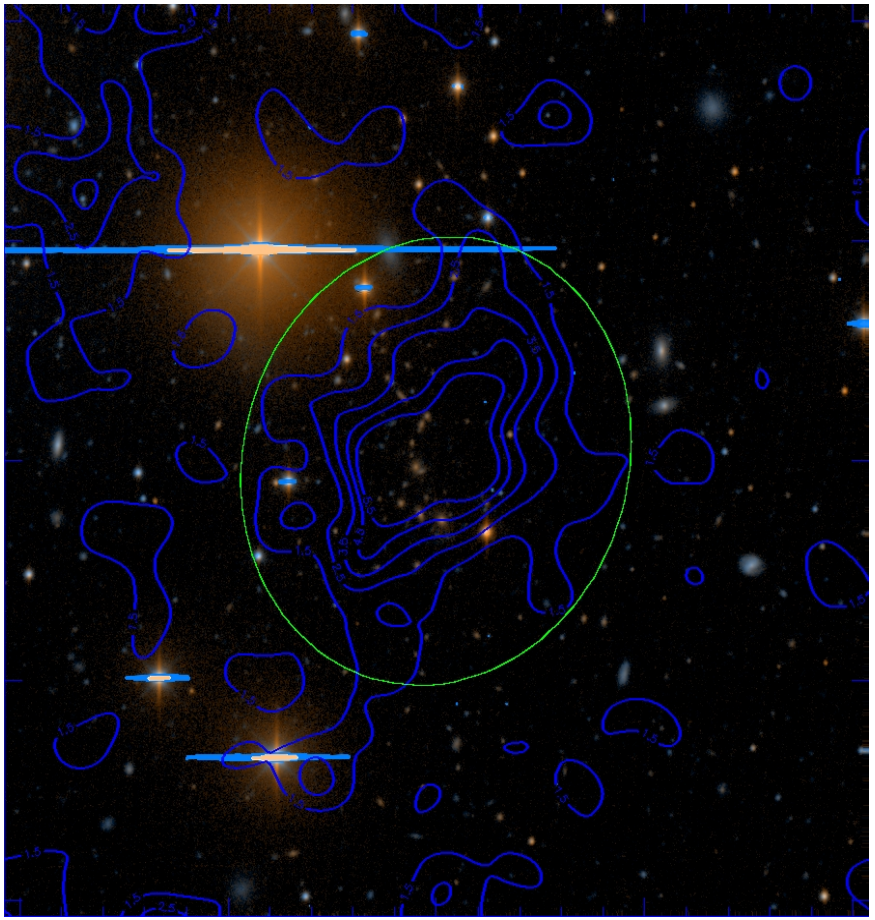
- Redshift estimation:
  - Select galaxies from within twice the X-ray extent of the cluster detected by XCS.
  - Assign each galaxy a redshift using the model.

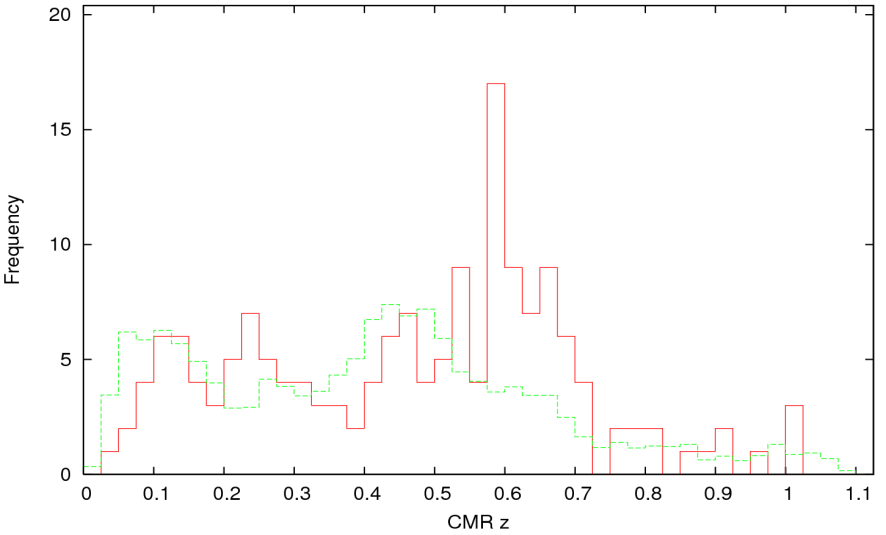
NXS Redshift Algorithm

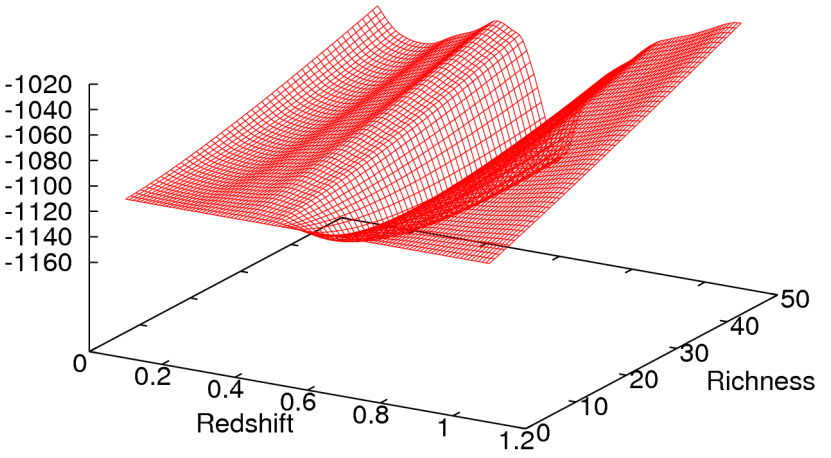
- Compare 'red sequence' colours of candidate galaxies to field sample (scaled to area of cluster candidate).
- Fit overdensity peak in colour=> red sequence redshift.
- Use an unbinned likelihood function (Cash 1979)
- Optimise on redshift: 0.1<z<1.0, Δz=0.01; cluster richness: 0<N<50, ΔN=1.
- Cluster model: Gaussian probability density function (e.g. Postman et al., 1996; Koester et al., 2007)
- Background model: histogram derived from NXS Field data

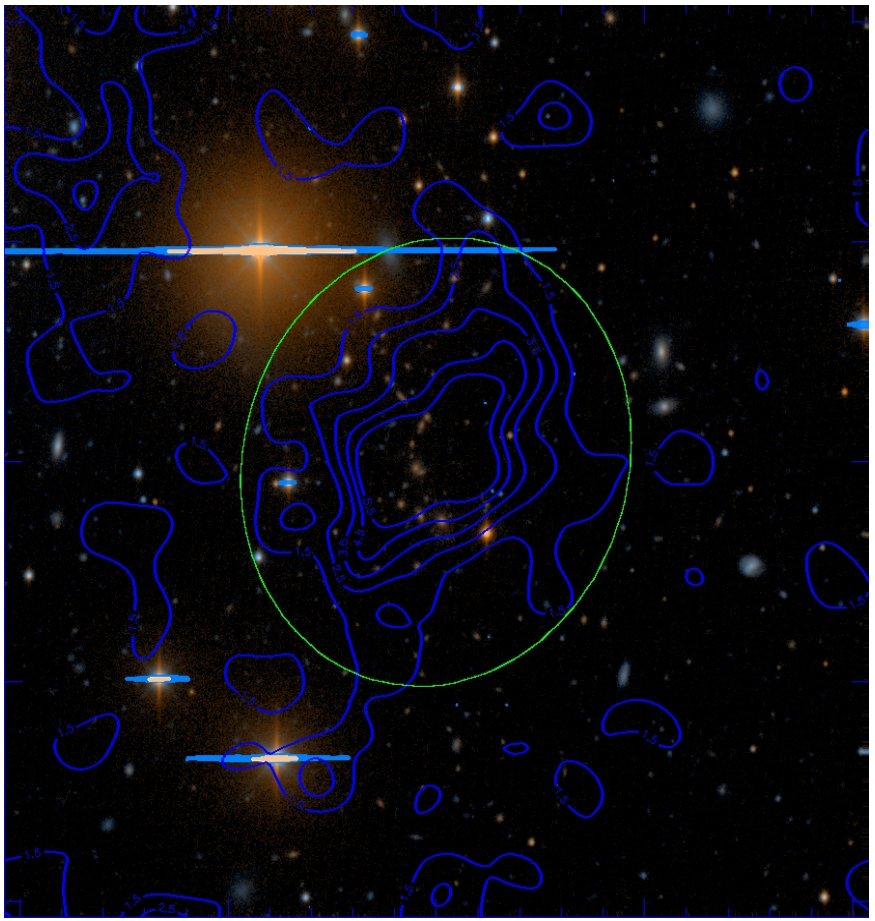


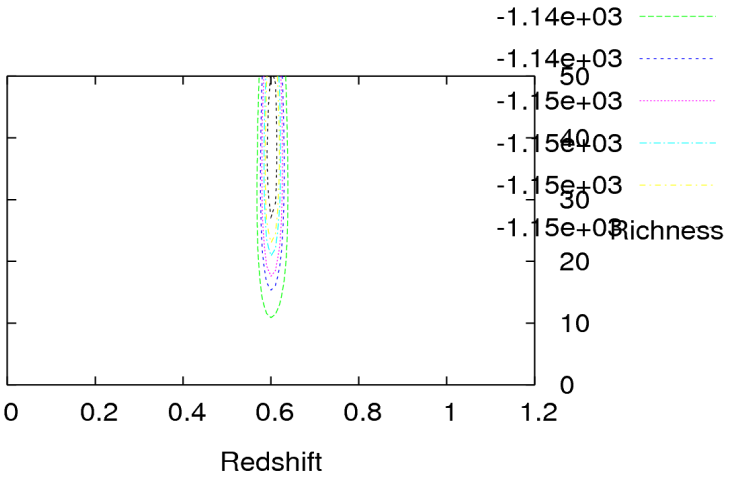





Frequency
CMR z
0
5
10
15
20
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1


-1020
-1040
-1060
-1080
-1100
-1120
-1140
-1160
0
0.2
0.4
0.6
0.8
1
1.20
Redshift
10
20
30
40
50
Richness

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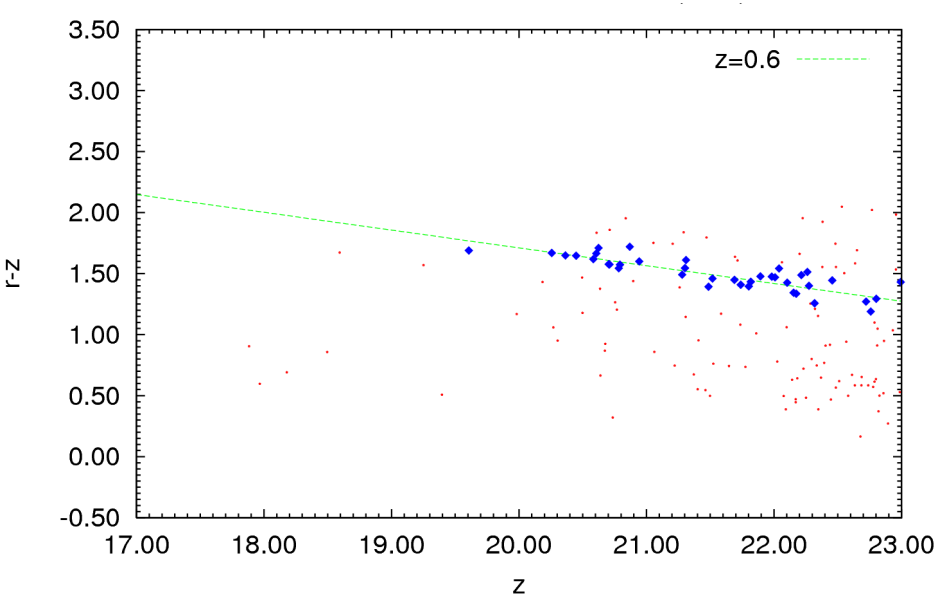
-1.14e+03
-1.15e+03
-1.15e+03
-1.15e+03
-1.15e+03
50
40
30
20
10
0
Richness
0
0.2
0.4
0.6
0.8
1
1.2
Redshift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3.00
2.50
2.00
1.50
1.00
0.50
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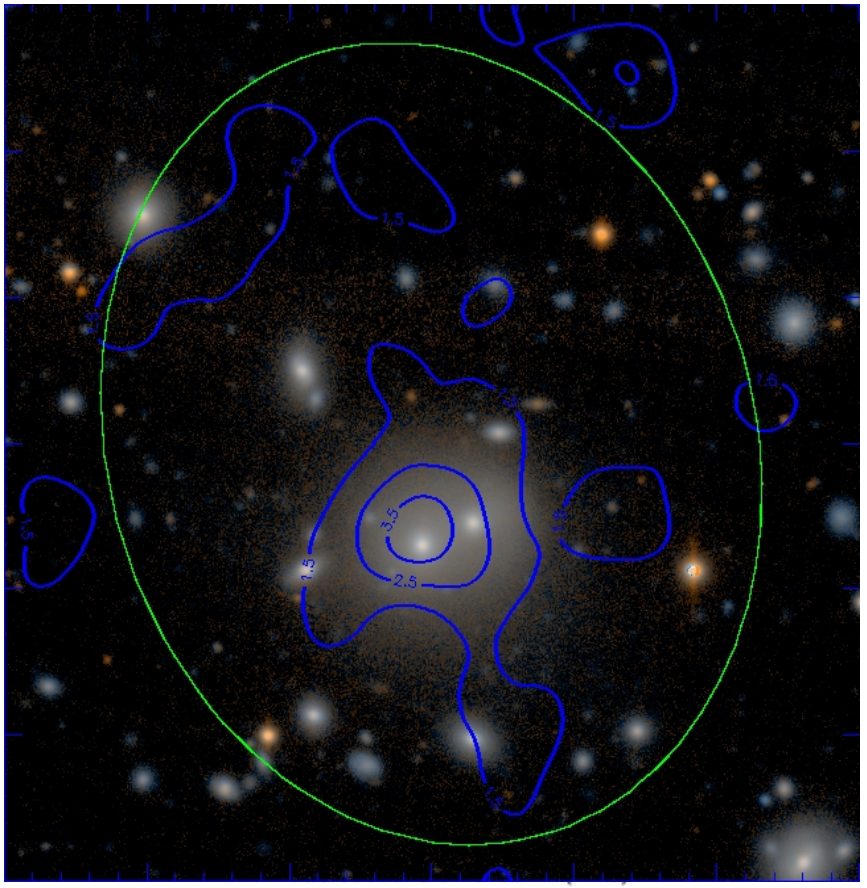
-0.50
r-z
17.00
18.00
19.00
20.00
21.00
22.00
23.00
z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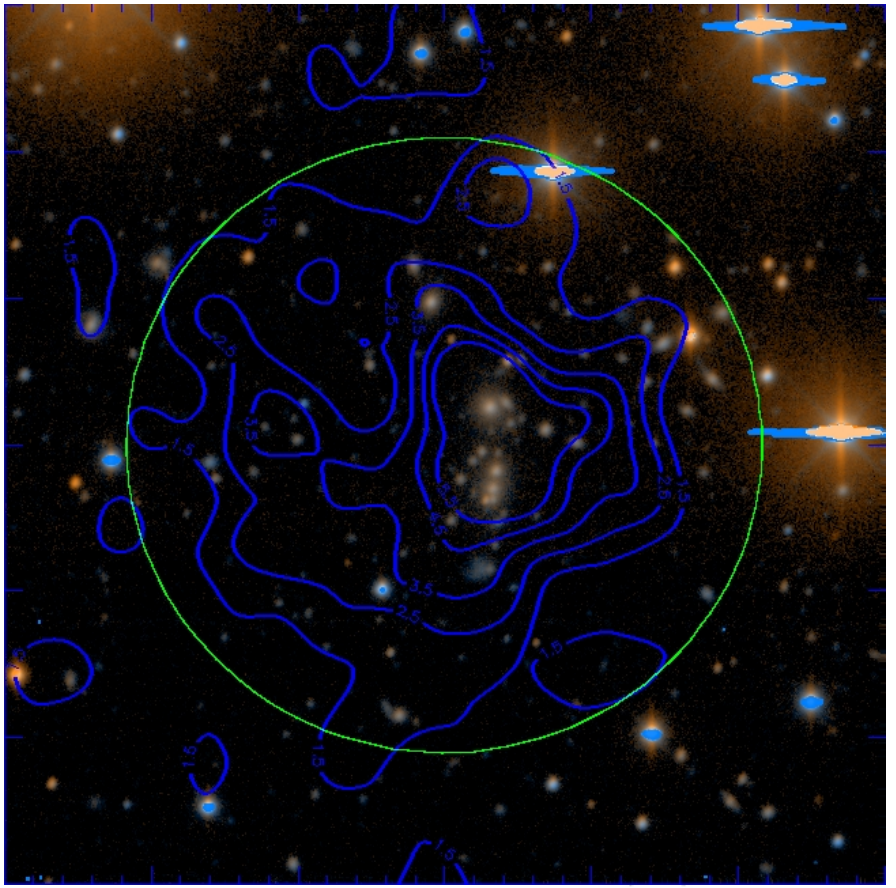
2.5
3.5


1.5
2.5
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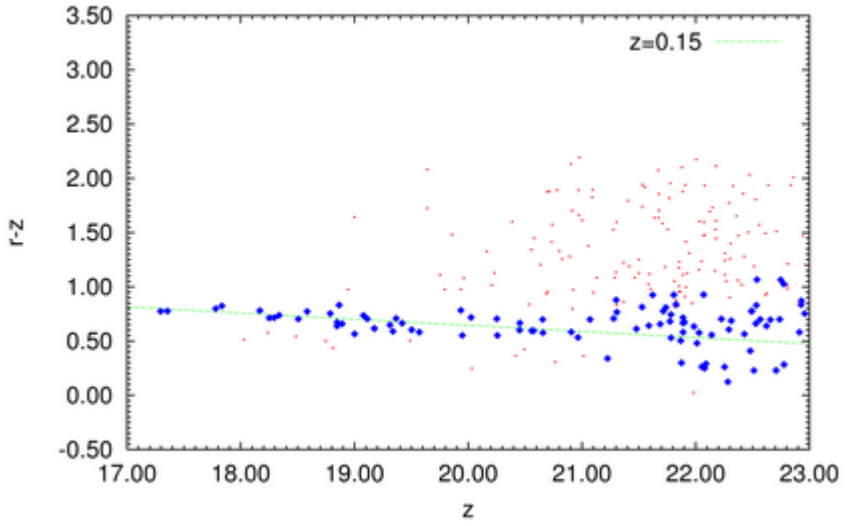
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r-z
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3.00
2.50
2.00
1.50
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18.00
19.00
20.00
21.00
22.00
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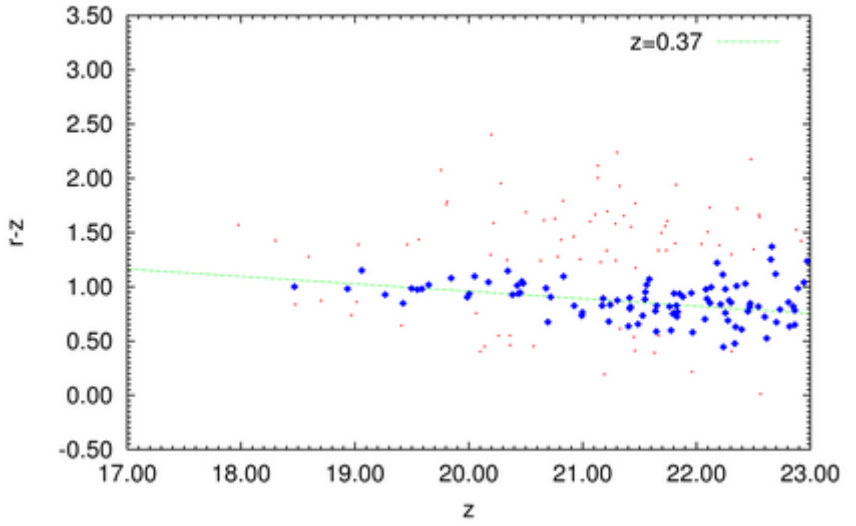
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r-z
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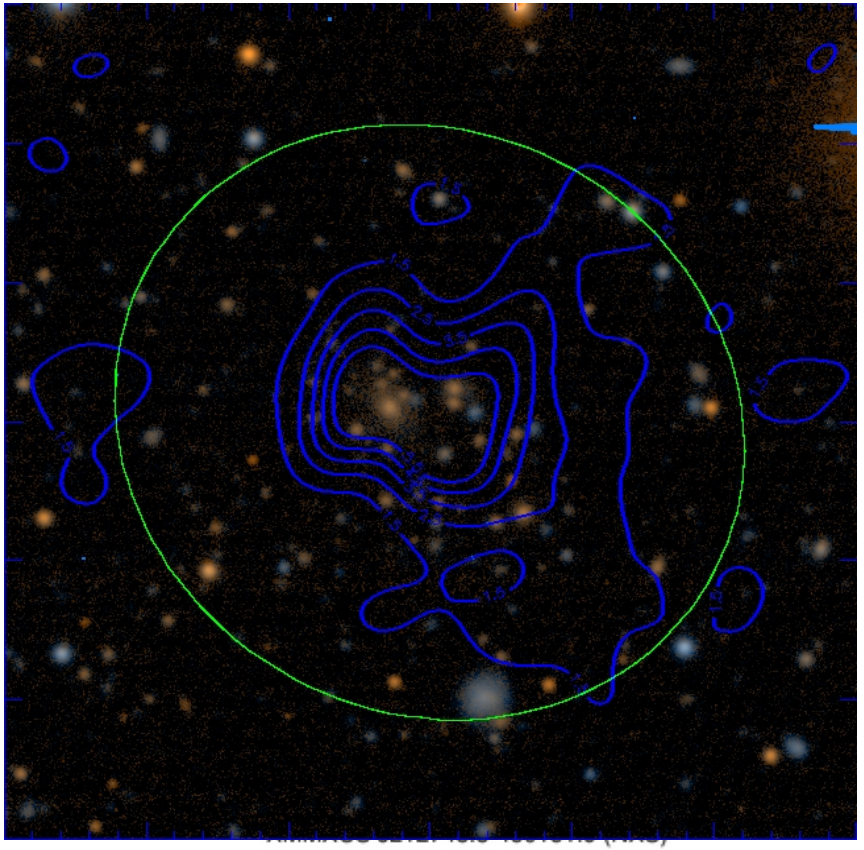
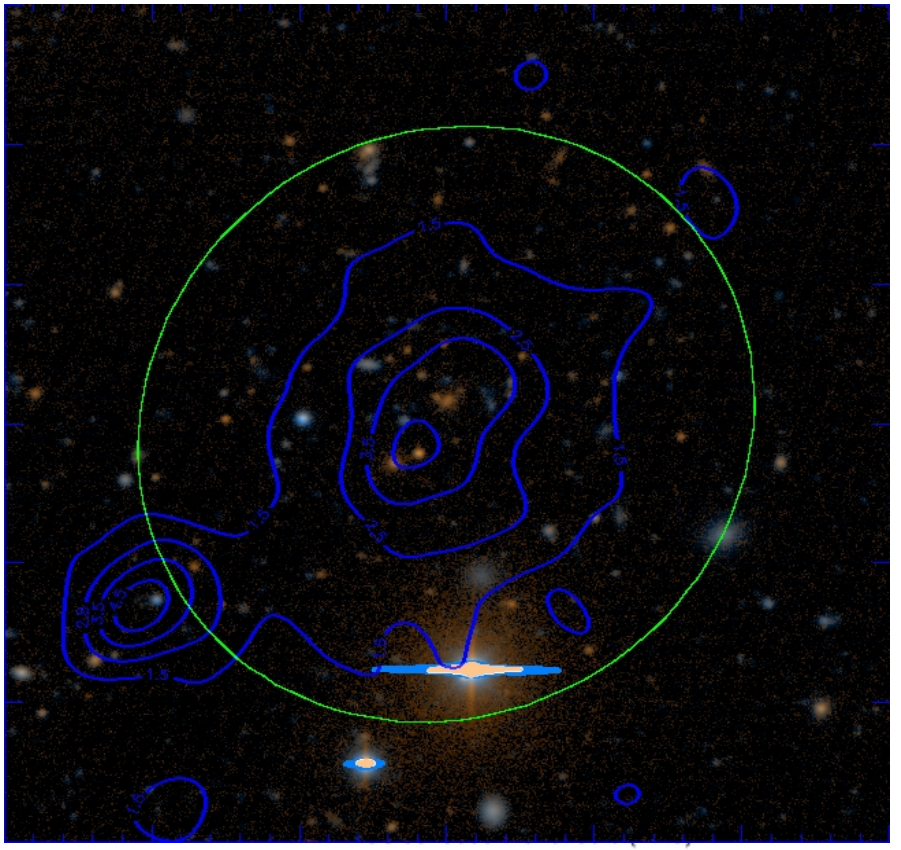
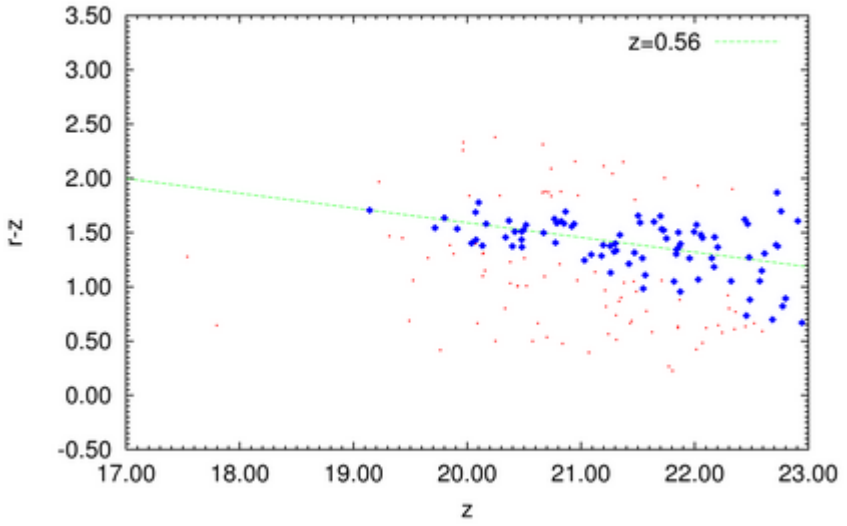
1.50
1.00
0.50
0.00
-0.50
17.00
18.00
19.00
20.00
21.00
22.00
23.00






z=0.56
r-z
z
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
-0.50
17.00
18.00
19.00
20.00
21.00
22.00
23.00

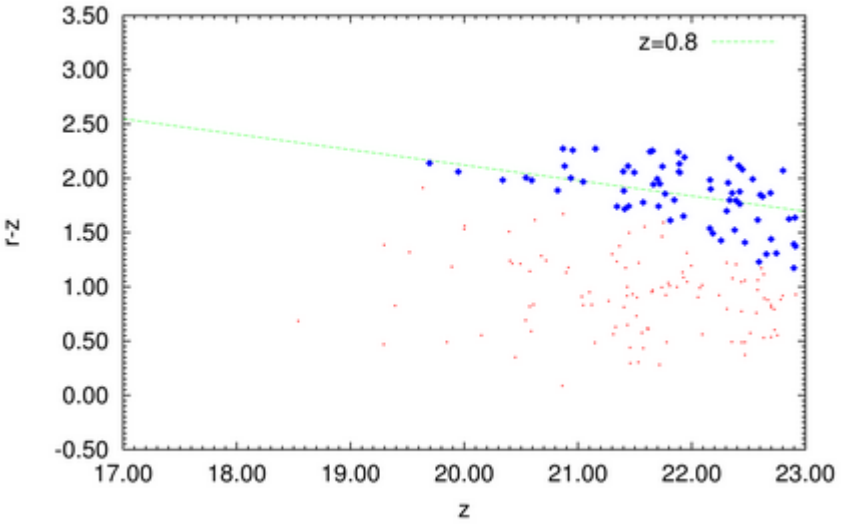
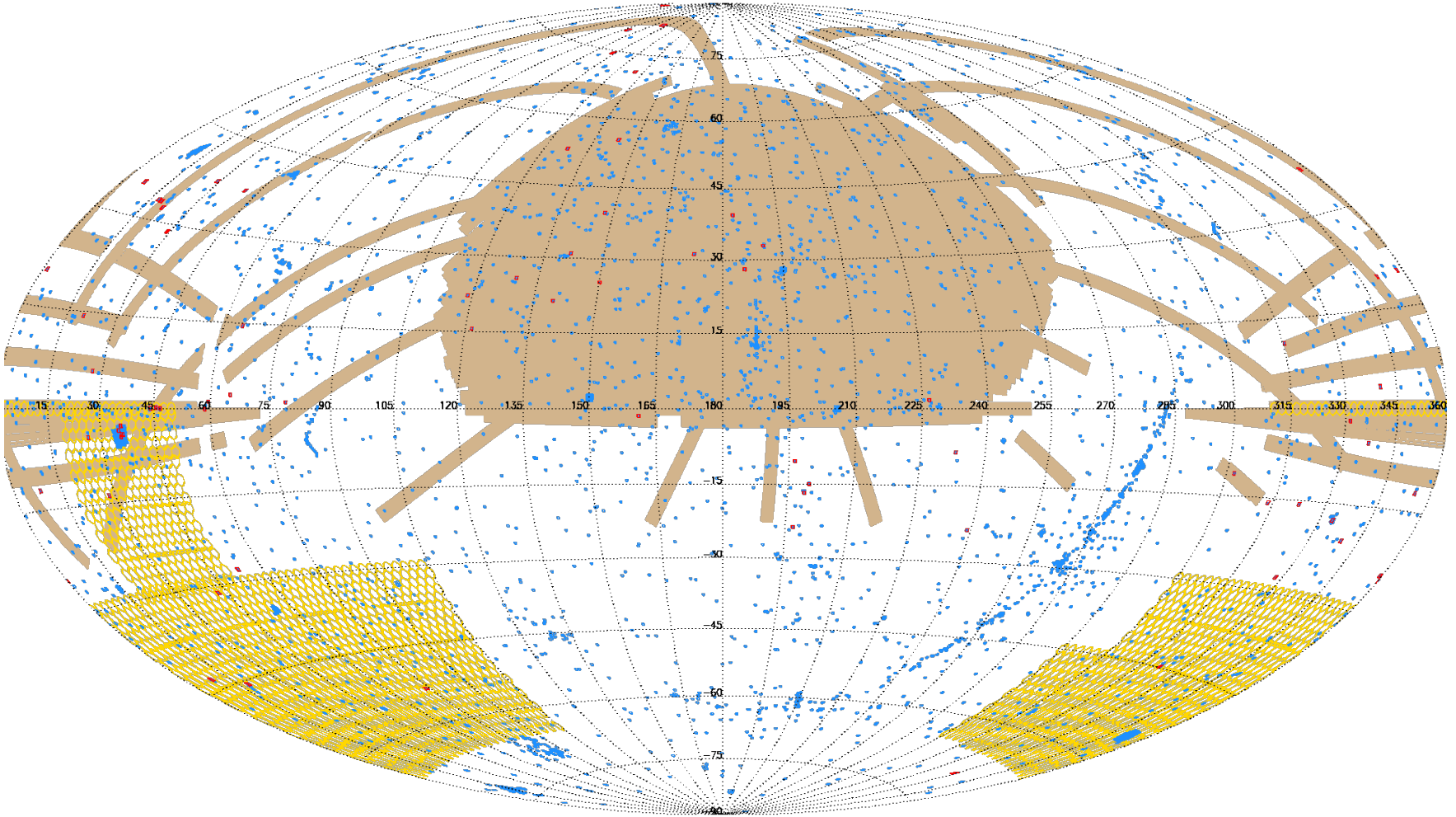

z=0.8
r-z
z
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
-0.50
17.00
18.00
19.00
20.00
21.00
22.00
23.00

Photo-z's from SDSS



- 1,149 cluster candidates in SDSS (z<0.5), 66 in stripe 82 (z<1.0)
- Universal field sample, candidates+known clusters/groups masked.
- r, z band imaging → red-sequence redshifts.

Cluster Zoo

XMM Cluster Survey

ty of Portsmouth.

XCS

XCS extended source identification

SDSS

Hello Kath! Click here to Log out

XCS classification page

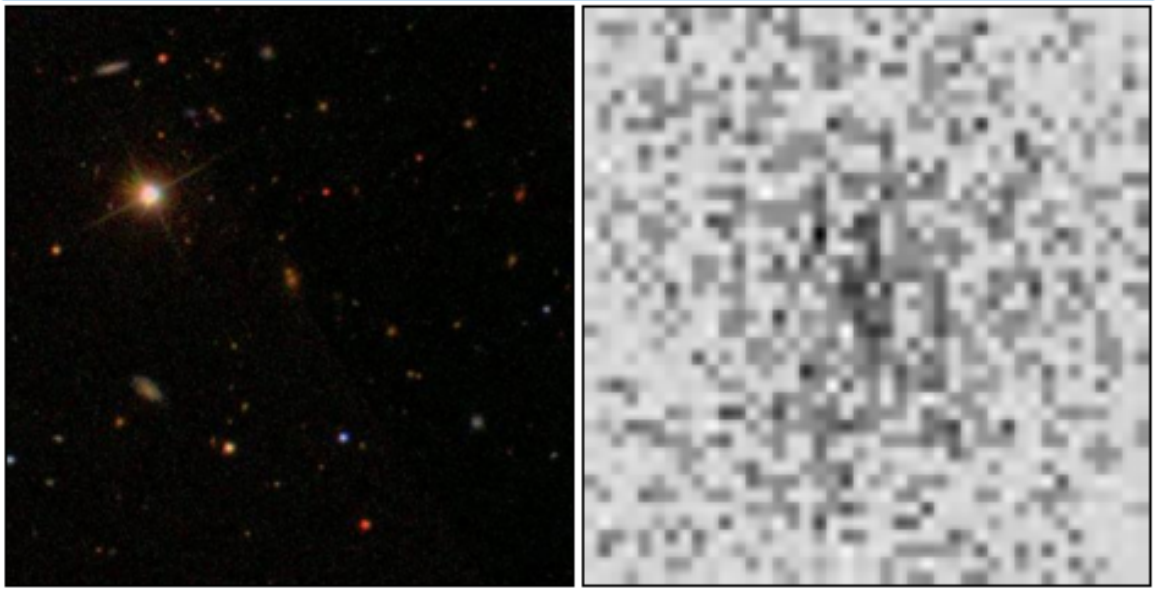
Please examine the figures found under the Optical&X-ray images and Raw data tabs, before making an extended source classification decision, under the third tab. This session you have made 0 classifications. Your target is 30. Access the classifications here

Optical&X-ray images | Mask data | Make your classification

Optical and Xray images

Scolling down the page displays images of the extended sources to be classified at three magnifications in the optical and x-ray. Simply moving [no need to click] your mouse over the contours: [on] and [off] links show and hide the contours, while [inv] inverts the sdss image, and highlights photometric objects. Don't like this cluster **Skip it here**.

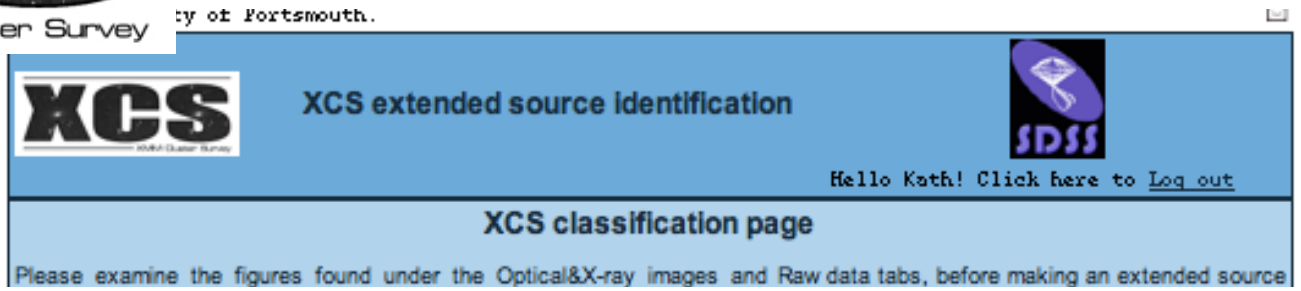
Magnification 3by3 acrmins contours: [on] [inv] [off]



Cluster Zoo

418 confirmed clusters

- NXS: 147
- SDSS: 274
- Stripe 82: 32



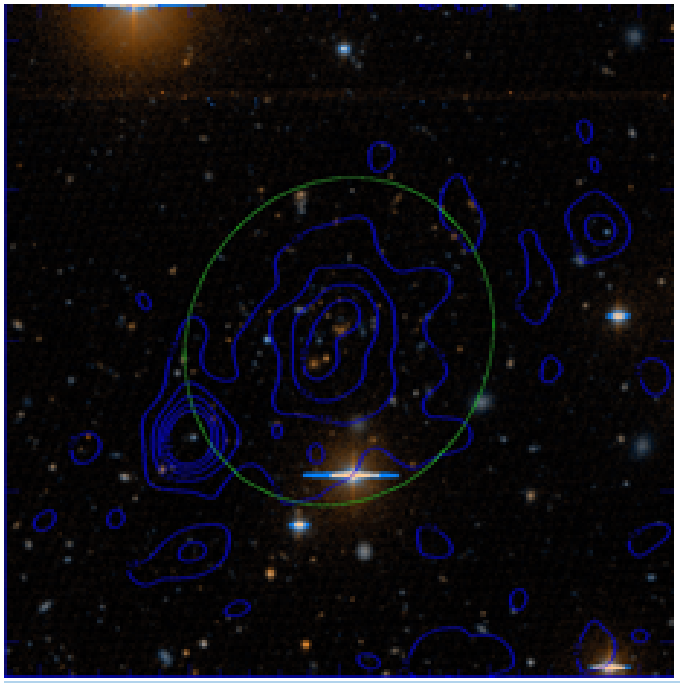
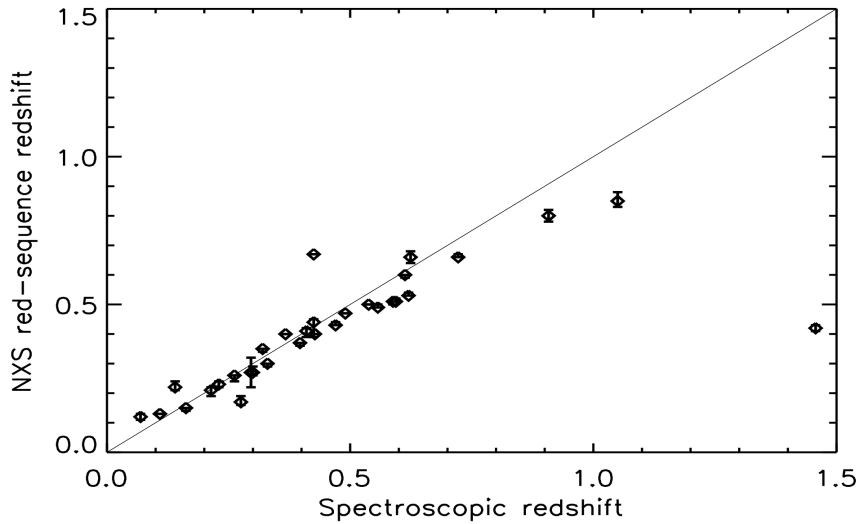
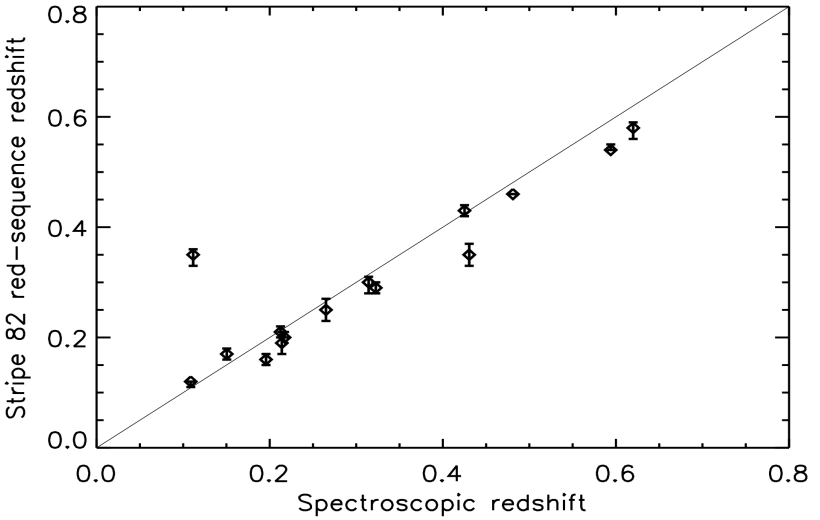
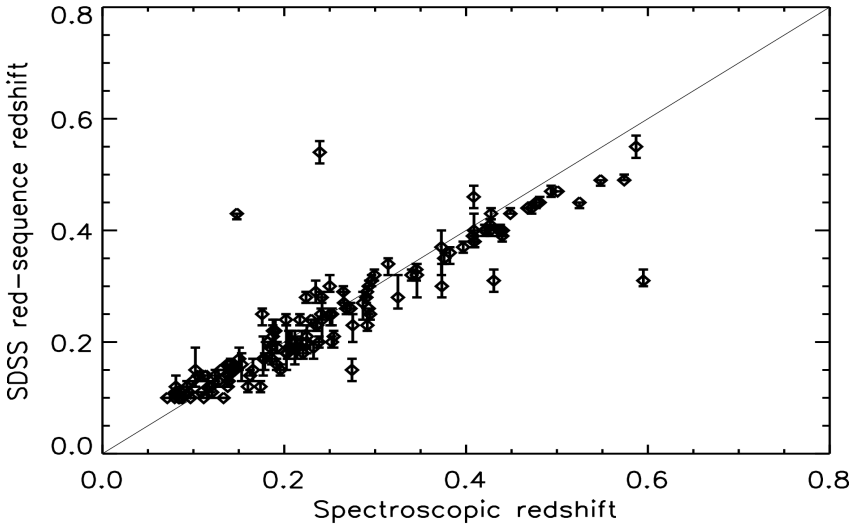


Photo-z vs spec-z







First data release

- >500 X-ray selected optically confirmed clusters
- 30 spec-z's obtained by XCS
- 120 from LRG spec-z's
- 220 photo'z from NXS/ SDSS/ Stripe 82.
- 150 previously known

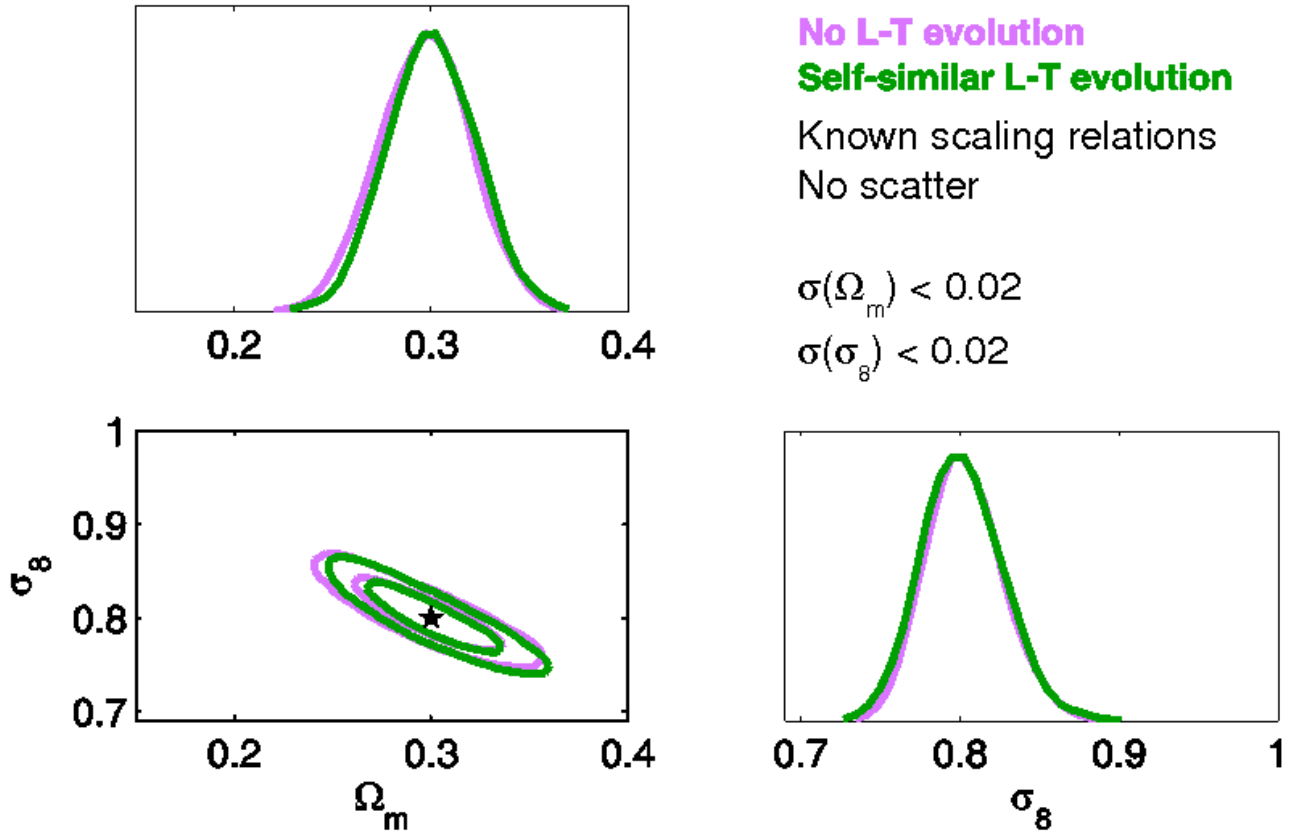
Current X-Ray Cluster Surveys

Stockholm University

Survey	Data	Clusters	Redshift range
HIFLUGCS	ROSAT	63	0.005 – 0.2
Maughan et al.	Chandra	115	0.1 – 1.3
O'Hara et al.	Chandra	70	0.18 – 1.24
400d	ROSAT/Chandra	86	0.35 – 0.9
XMM-LSS	XMM	29	0.05 – 1.05
Mantz et al.	ROSAT/Chandra	238	0.05 – 0.45
Peterson et al.	Chandra/XMM	723	0 – 1 ?
XCS_{300} (230 □°)	XMM	450	0.003 – 1.457

Expected constraints

- Not including measurement errors (T, z):



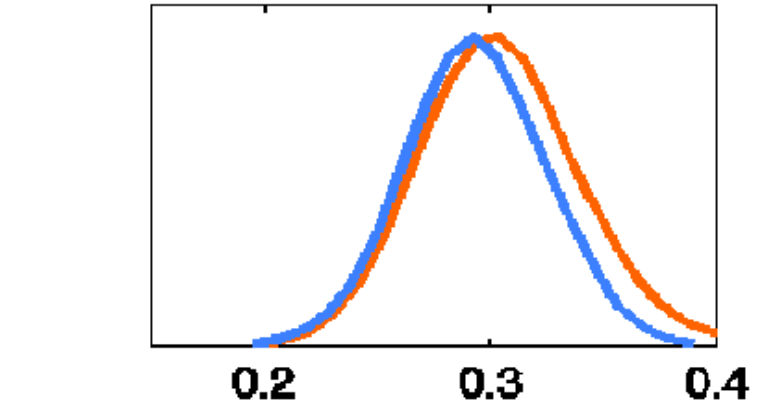
No L-T evolution
Self-similar L-T evolution
Known scaling relations
No scatter

$\sigma(\Omega_m) < 0.02$
$\sigma(\sigma_8) < 0.02$

- Parameter constraints from n(M,z) (Sahlen et al. 2009)
- Based on mock LCDM cosmology, selection function and M-T relation.

Expected constraints

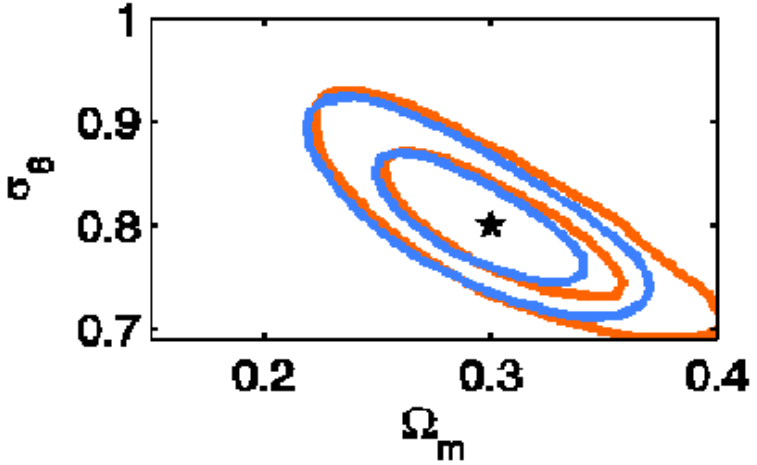
- Not including measurement errors (T, z):

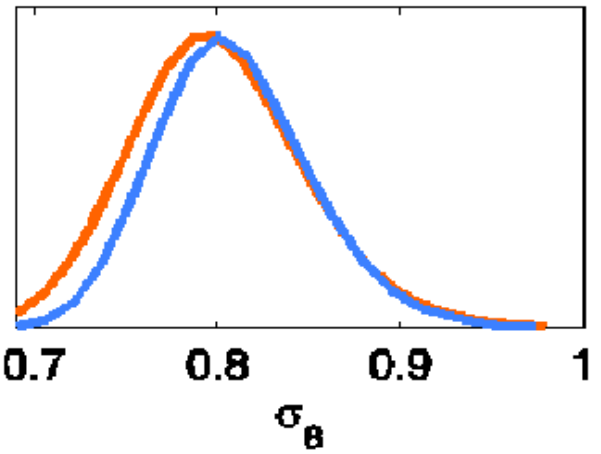


No L-T evolution
Self-similar L-T evolution
Self calibration
With scatter

$\sigma(\Omega_m) < 0.03$

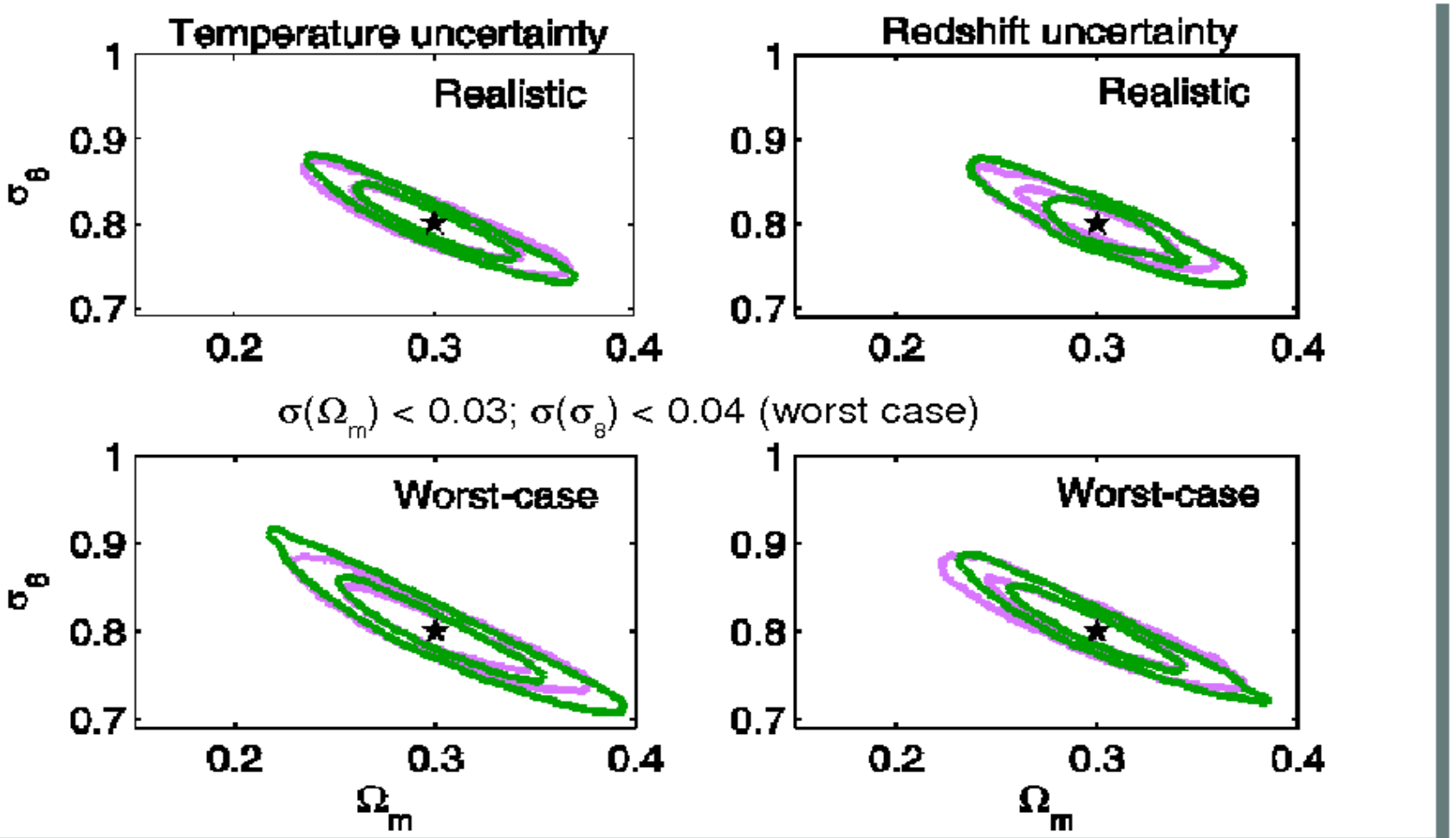
$\sigma(\sigma_8) < 0.05$



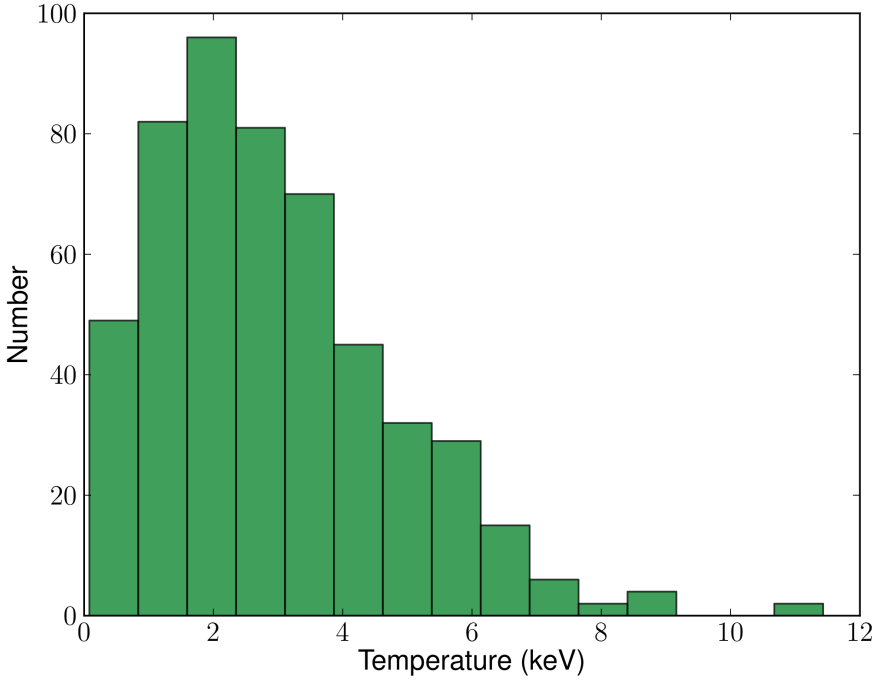


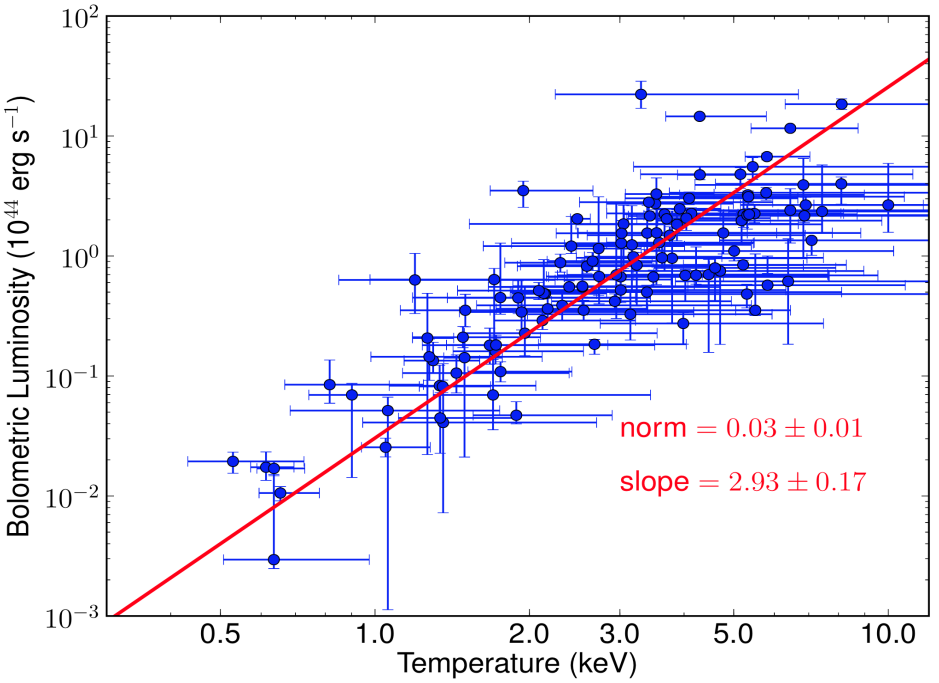
Expected constraints

- Including measurement errors (T, z), known scaling relations:



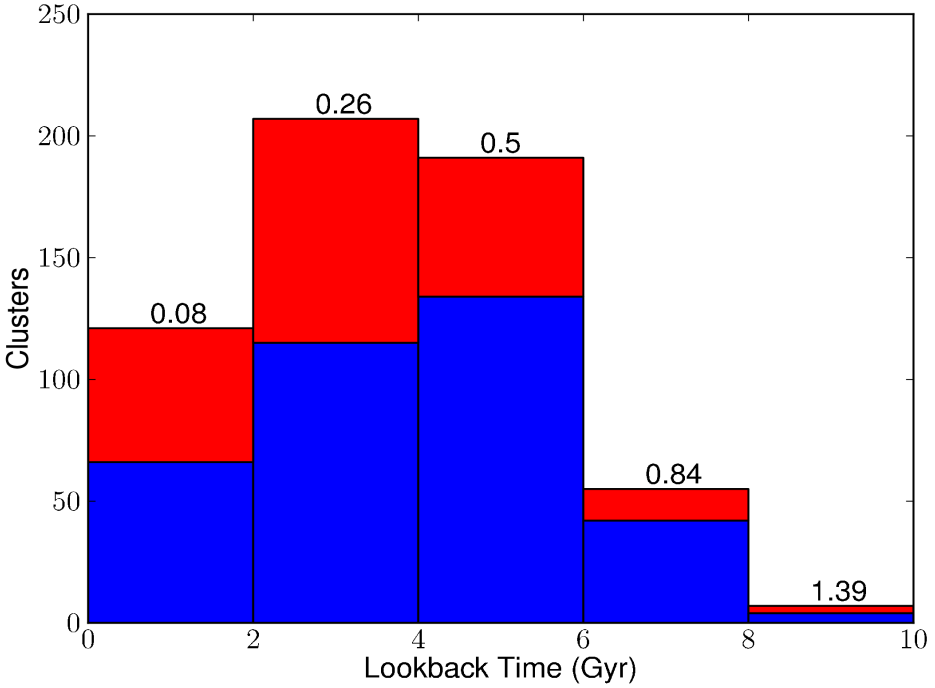
Preliminary Lx-Tx relation

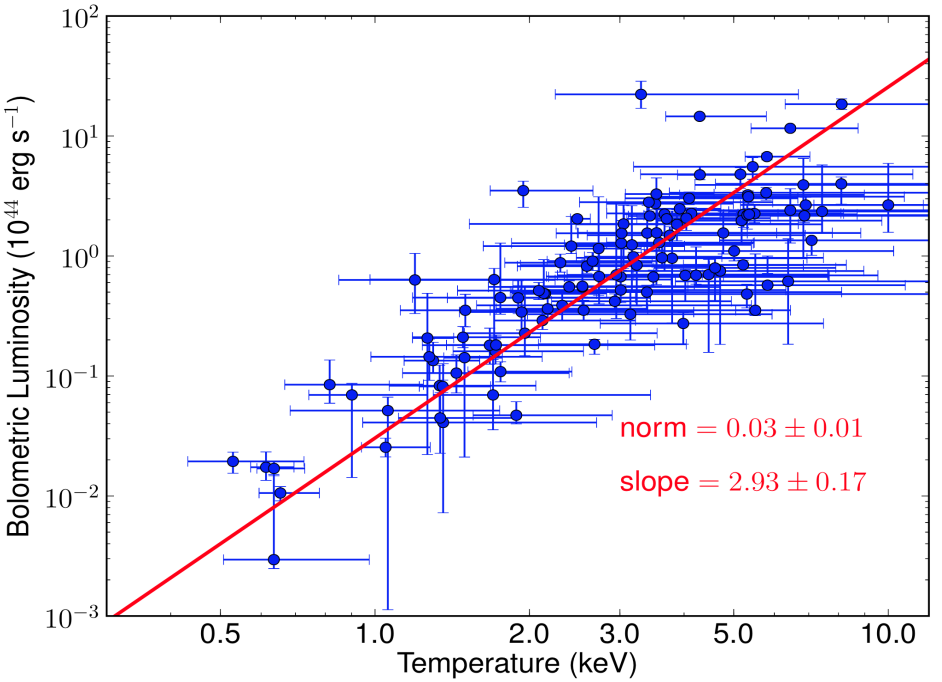




- L-T based on 118 clusters
- Selection function not included
- Lloyd-Davies et al. in prep.

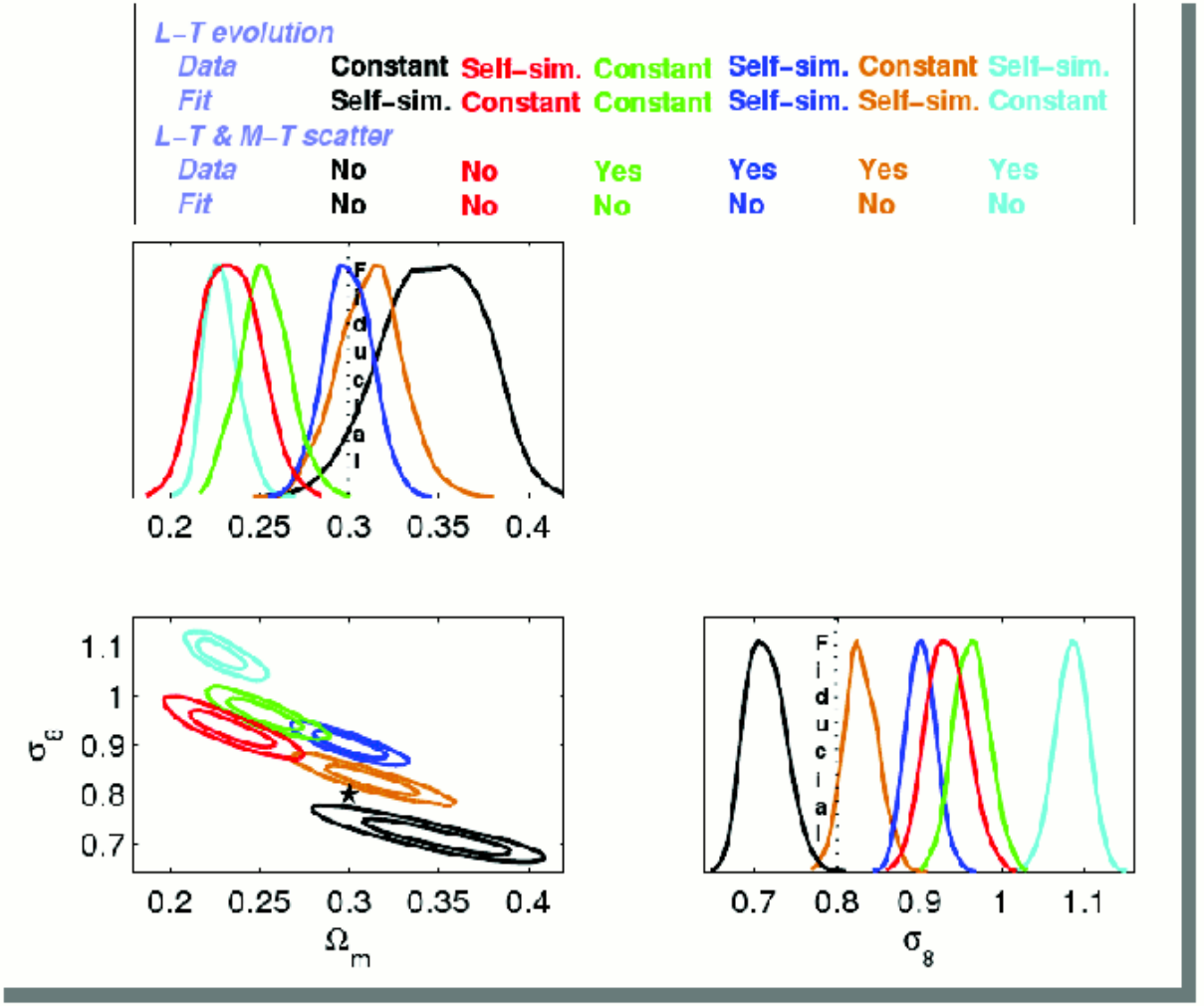
Preliminary Lx-Tx relation





- Can probe evolution of L-T relation
- Lloyd-Davies et al. in prep

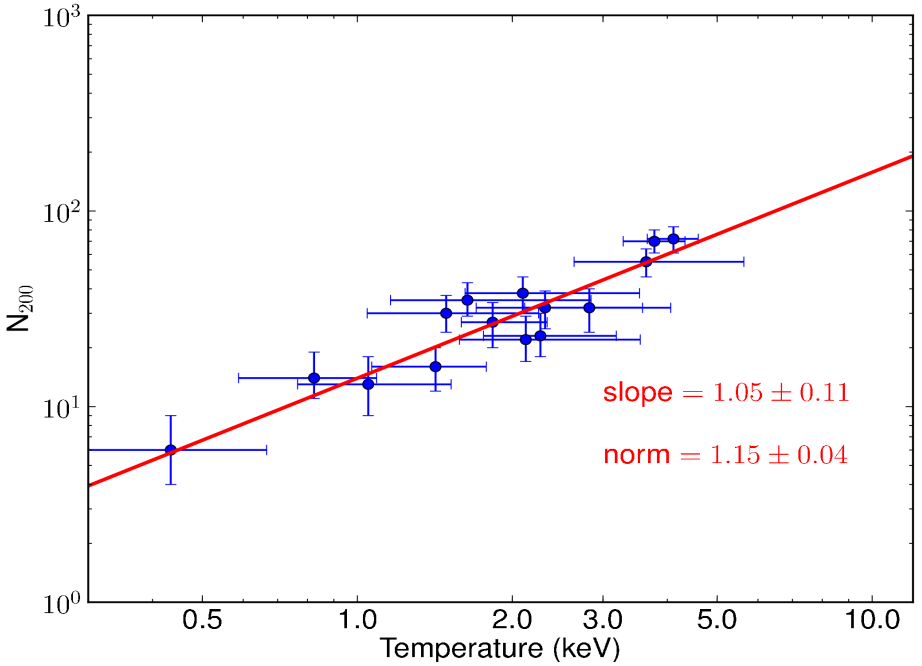
- Making incorrect assumptions about the evolution of scaling relations leads to large systematic errors in derived cosmological parameters (Sahlén et al. 2009)

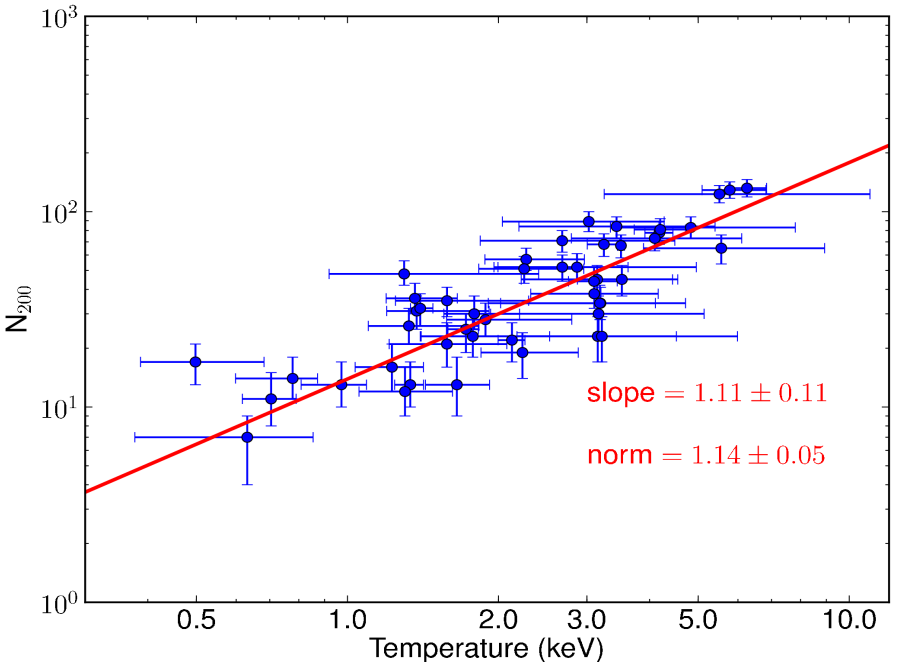


XCS Optical-X-ray Scaling Relations

- Ngals and Lopt vs X-ray Temperature and X-ray Luminosity.
  - Important for optical cosmology surveys (i.e. DES) using optical data alone to infer cluster masses.
- HOD
  - Important for DM simulations.
- No uniform measure of richness; using MAXBCG method (Koester et al 2007).
  - Galaxies within 2sigma of red sequence colour.
  - Rvir (from measured temperature).
  - 0.4L* => z=0.3 for SDSS clusters; z=0.8 for NXS and Stripe 82.

Preliminary N200-Tx relation





Summary

First XCS data release of >500 X-ray selected, optically confirmed clusters

Largest homogeneous sample of X-ray selected clusters with temperature measurements

Beginning science exploitation phase

Constrain cosmological parameters

Evolution in L-T relation

Optical to X-ray scaling relations with view to DES